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A COMPARISON OF METHODOLOGIES IN THE MEASUREMENT OF OLFACTORY SENSITIVITY UNDER CONDITIONS OF NON-ADAPTATION AND CO-ADAPTATION

by

JOHN WILLIAM FRASER B.Sc., Dip.Ed.

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DECLARATION

To the best of my knowledge, this thesis contains no copy or paraphrase of material previously published or written, except when due reference is included in the text.

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CONTENTS

ABSTRACT

An investigation into the relative efficiency of Threshold and Signal Detectability measures of olfactory sensitivity was undertaken using isopropyl alcohol as stimulus. Intensive testing of seven subjects under adaptive and non-adaptive conditions revealed that the Signal Detectability paradigm, although theoretically desirable because of its allowance for the subject's response bias, was difficult to implement because of the prolonged testing required. A variance of the rating technique involving multiple stimulus concentration presentations in a three-hour testing session was attempted. Results in the non-adapting environment indicated that the method was more effective than single-stimulus concentration presentations. However reliable results under adapting conditions were obtained in the case of one subject only.

As a comparison, the constant stimulus method was used to obtain threshold using a procedure similar to Cheesman's and Mayne's group threshold determinations, but modified for individual subject testing. Practice and learning effects were noted and their relevance discussed. The Cheesman hypothesis viz. that adapting odour concentration and threshold elevation obey a linear logarithmic relation which is characteristic of the adapting and test stimulus compounds was confirmed in two subjects only. Reasons for non-confirmation include the extended adapting stimulus concentration range, subject boredom and inadequate control of the stimulus, the latter factors being a consequence of prolonged testing.

The sniff-bottle and air-dilution forms of stimulus presentat-

ion were employed, although not with the same subjects. Thus a direct contrast of these presentation methods was not possible. However results were generally more consistent with the air-dilution technique.

The feasibility of an odour classification based on subject responses during adaptation rather than on molecular parameters was evaluated and the difficulties likely to be encountered in employing Signal Detectability measures of sensitivity was discussed.

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CHAPTER 1

CHAPTER 1.

THE OLFACTORY SYSTEM IN MAN

The sense of smell is of reduced importance in man compared to the lower animals whose survival is often dependent on its adequate development. While the external organ is relatively large, the olfactory brain (rhinencephalon) is diminished so that some areas such as the olfactory tubercle, although prominent in macrosmatic animals, are rudimentary in man.

Anatomically and operationally the olfactory sense is a long-range system in that any stimulus presented to it must traverse the nasal passages before impinging upon the receptors of the olfactory membrane located high in the nasal cavity. Schneider (1967) suggests that only three or four percent of odourous molecules present at the nasal opening reach the olfactory membrane thus making stimulus quantification indeterminate. Once the molecules have made contact with the receptor cells, electrical impulses are generated which pass into the olfactory nerve (Cranial Nerve I) and thence to the glomeruli of the olfactory bulb where 1,000:1 convergence occurs. From here they pass to the mitral cells and thence to the stria and olfactory areas along the olfactory tract. Co-laterals from the grey matter lining the olfactory bulb contribute to the impulses along the olfactory tract. In this way impulses from the contralateral olfactory bulb can modify incoming information. Nerve endings from the trigeminal nerve (Cranial Nerve V) are present in the olfactory membrane and are stimulated by certain odours. Hence subject responses to odourous stimuli need not be a direct result of stimulation of olfactory receptors, but may be due to trigeminal nerve

effects, particularly when the subject reports the presence of an odour with emphasis upon hedonic and irritant properties.

The specificity of neurons comprising the olfactory bulb and the nature of the convergence of the olfactoria fila has prompted speculation concerning the mechanism of odour discrimination. Walsh (1956) has investigated the electrochemical characteristics of three types of neurons having different functions in the olfactory bulb of rabbit. On the other hand, Adrian (1950) and Mulvaney and Heist (1970) suggest that discrimination is achieved by spatiotemporal means.

There is physiological evidence supporting some of the major psychophysical propositions in relation to the olfactory modality. Slow electrical changes occur at the olfactory epithelium under stimulation. Ottoson (1956) has found that the relation between the amplitude of response in frog epithelium and the strength of stimulation resembles the human psychometric function. Electrical stimulus reception in receptor cells gives rise to a spike potential during which the intrinsic activity of the olfactory bulb is disrupted (Adrian, 1950), thus lending support to the Signal Detectability paradigm which assumes that signal is superimposed upon a continuous background of neural noise. Thus there is some justification for using Signal Detectability techniques in olfactory psychophysical experiments.

No direct relationship exists between overall brain size and olfactory acuity (Mulvaney and Heist, 1970). The relative size of the rhinencephalon decreases as one ascends the phylogenetic scale so that man and the primates are microsmatic. Nevertheless man's sensitivity to odours is high. It seems that functional aspects of olfactory sensitivity are sometimes confused with absolute sensitivity per se. Animals with proportionately larger olfactory brain areas are more reliant on them for survival and make more use of them than does man e.g. pheromones

aid in signal communication and act as initiators of fixed action patterns (Comfort, 1971).

Olfactory defects include hyperosmia, hyposmia and anosmia. The aetiology of an anosmia may be congenital, hysterical or the result of a local disorder. Zwaardemaker (1891) regarded most congenital anosmias as having a "nervous characteristic" which could be of use in the clinical examination of patients with nervous disorders. However, his primitive olfactometer, which was based on a false premise regarding odour saturation, did not permit valid quantitative investigation. The potential usefulness of a study of olfactory defects is twofold. Firstly, one can ascertain the degree to which the trigeminal component of an odour contributes to subject response and secondly, one can use the incidence of anosmia as an adjunct to the search for primary odours (Amoore, Venstrom and Nutting, 1972).

Brown, Maclean and Robinette (1968) criticize the lack of population studies in olfactory research and also the tendency of researchers to employ only those subjects who satisfy arbitrary sensitivity requirements. Ability (or inability) to detect an odour may be partly genetically and physiologically determined and the mode of detection highly subject specific. Although Brown et al. found that thresholds were unimodally distributed in seven out of eight compounds studied, they suggest that further research on odour sensitivity distributions could reveal discontinuities which might lead to a greater understanding of the aetiology of olfactory defects and the mechanism of olfactory stimulation. The magnitude of such investigations is exemplified by a study conducted by Patterson and Lauder (1948) who tested 4,030 subjects with a 0.0075% solution of butyl mercaptan. Seventeen "anosmics" were found, only eight of whom were considered to be suitable for postulating hypotheses concerning modes of inheritance.

Differences in olfactory sensitivity between men and women have been observed (Bailey and Nichols, 1884; Schneider and Wolf, 1955; Venstrom and Amoore, 1968; Koelega and Köster, 1973). Variables such as the nature of the test stimulus, the time of testing and subject's age have been fully investigated to allow general statements regarding sensitivity differences. In females, variability in sensitivity with the menstrual cycle is most evident when substances with some sexual significance are used e.g. exaltolide (Le Magnen, 1952). This has prompted speculation concerning the role of the olfactory system in sexual functioning. Concentrations of female hormones such as oestrogen and progesterone have been correlated with olfactory sensitivity (Vierling and Rock, 1967). The exocrinological theory (Parkes and Bruce, 1961) is based on the hypothesis that the presence of male odours may affect secretion of female hormones. Thus normal menstrual variation in the sensitivity of females to certain odours could be confounded by the frequency and degree of contact with males.

THE RELATION OF SMELL TO THE OTHER SENSES

The sense of smell exhibits features such as adaptation and absolute and differential thresholds which are common to other senses. The most striking differences, other than obvious anatomical ones, involve the physical parameters of the odour stimulus and psychological description. Whereas the link between parameter and description is clearly understood in the case of vision and audition (e.g. wavelength-hue and frequency-pitch relationships), this is not the case in olfaction.

Experimental studies in olfaction may be broadly classified into two groups: those in which emphasis is on stimulus parameters such as molecular characteristics and those in which the subjective responses to stimuli are paramount. Many attempts have been made to combine

information from both types of experiment. The numerous theories of mechanism of olfactory stimulation stand in contrast to the relative paucity of experimental evidence supporting them. This reflects the unique methodological difficulties encountered in olfactory research as well as the inadequate vocabulary of odour description.

The Trichromatic Theory of colour vision put forward by Young (1807) and developed by Helmholtz (1852, 1866) has initiated a search for primary odours by analogy. Multidimensional scaling techniques have been used in attempts to classify odours (Yoshida, 1964; Mitchell, 1971; Berglund, Berglund, Engen and Ekman, 1972); the latter study following procedures used in colour analysis. Also adaptation effects of one odour on another should yield some information concerning odour relationships which could be used to classify odours into primary groups. The relatively large informational capacity of the olfactory system for qualitative discrimination (Engen and Pfaffman 1959; Wright, 1964) points to the existence of at least twenty-five primary odours compared to the three primaries in the case of colour.

Adaptation is considered to be primarily a central phenomenon (Adrian, 1950). Intra-sensory masking experiments in audition and vision show an increase in the exponent on the psychophysical function (Stevens, 1966) whereas a decrease is noted in olfaction (Mitchell and McBride, 1971). Mitchell and McBride suggest that differing experimental restrictions may account for these results. The "single-channel hypothesis" (Welford, 1960) presupposes a common mechanism of filtering out signals which are either non-essential or are presented too rapidly for the observer to perceive in toto. Moreover the hypothesis is applicable to all modalities. Bisensory presentation experiments are confined to auditory and visual senses at present. The possibility of the olfactory sense response being partly determined by non-odourous

stimuli has important consequences for experimenters who attempt to control environmental variables. The lack of standardization and reproductability of olfactory sensitivity measures between experimenters is directly related to this point.

The theory of Signal Detectability, originally formulated within visual and auditory senses has only recently been incorporated into olfactometry (Semb, 1968) yet is was used in gustatory studies as early as 1964 (Linker, Moore and Galanter, 1964).

It can be seen that the similarities between the sense of smell and the other senses are most evident with respect to psychophysical characteristics. Anatomical and physiological differences are the limiting factors in the olfactometric application of psychophysical techniques derived from studies of the visual and auditory senses. These factors influence the way in which quantification and presentation of the stimulus are dealt with in olfactory experiments. A detailed discussion of stimulus quantification and presentation appears in the following chapter.

CHAPTER 2

CHAPTER 2.

STIMULUS QUANTIFICATION AND PRESENTATION

Historically, quantification as well as presentation of odourous stimuli in psychophysical experiments may be divided into two lines of development: liquid dilution versus air dilution techniques and controlled (injection) presentation versus the natural sniff.

Very few liquids are completely odourless and thus suitable for use as diluents. Water, the most common diluent, has a characteristic "flat" odour in its distilled form. Diethyl phthalate (Semb, 1968), benzyl benzoate (Beck, Kruger and Calabresi, 1954) and silicon oil (Berglund, Berglund, Engen and Ekman, 1972) have been used as diluents. It must also be considered that the chemical interaction between solute and solvent may produce small quantities of compounds which act as impurities giving rise to changes in qualitative odour characteristics and hence influence quantitative judgments. In addition, the solubility of test compound in diluent is temperature dependent, the degree of it being a function of molecular characteristics and the kinetics of the solution system. It is therefore not possible to assume ideality despite the low solution concentrations used in olfactometry. Thus vapour concentration, the most common method of expressing stimulus intensity, may not be directly related to solution concentration.

The limited range of odourless liquid diluents available and their uncertain interaction olfactorily with test stimuli has prompted the use of pure air as a universal diluent. Wenzel (1948) gives a comprehensive review of techniques utilizing air dilution (and liquid dilution) from 1850 - 1948.

The primitive olfactometer designed by Zwaardemaker (1904) for use in clinical investigations incorporated an indirect measure of stimulus strength, the olfactie. The assumption implicit in its use was chemically unsound in as much as the degree of vapour saturation was not related linearly to the extent of exposed stimulus since increases in vapour concentration were not possible beyond saturation at a particular vapour pressure (Gundlach and Kenway, 1939). More recent attempts at accurate stimulus quantification have incorporated direct measures based on molecular concentration at the saturated vapour pressure of the test liquid and subsequent air dilution. Saturation is achieved by allowing a stream of pure air either to pass over undiluted test liquid at a predetermined constant temperature (Cheesman and Kirkby, 1959) or by sparging air through the test liquid (Ough and Stone, 1961). Continuous dilution is achieved by combination of air and odour lines according to flow rates calibrated at a standard pressure difference. The time lag involved in changing from one test concentration to another coupled with adsorption of odours by glass flow lines has furthered the use of group studies in which subjects undergo a limited number of tests per session. (Cheesman, 1955).

THE CHEESMAN AIR-DILUTION OLFACTOMETER

The prototype apparatus described by Mayne (1953) was based on the principle that the saturated vapour pressure of an odour is a reliable measure of concentration. Later developments (Cheesman and Kirkby, 1959; Cheesman, 1972) have either been of a sophisticated nature (e.g. separating functional components from the area in which the subject operates) or discarding unnecessary features (e.g. constant pressure bottles). The main components of the apparatus consist of a source of compressed air, an air purifer, a saturator and thermostat, capillaries

for air and odour lines, an especially designed smelling point and an exhaust system. The arrangement of these components is shown in Fig. 1. The apparatus is composed of glass connections with hemispherical and conical ground joints. Air is forced through the system from a cylinder of compressed air at the rate of 12 litres/minute so that a pressure difference of 5 cm. of head of water is maintained in the air and odour distributing lines. This is monitored by means of large dial-type manometers situated at a considerable distance from the smelling points. The air purifier consists of an ethyl alcohol - dry ice bath which has proved to be more reliable than activated carbon filters. A coil of copper tubing, the only non-glass connection in the whole apparatus, passes from the air cylinder, through the air purifier and on to the saturator.

The saturator is of such a design that complete saturation is attained without interuption to the air flow. It is based on a design put forward by Lord Berkeley and Hartley (1908) and incorporates a continuous flow of air over the test liquid contained in six conjoined glass chambers of 25 cm. in length and 2 cm. in diameter. The low dilutions used at threshold concentrations necessitate the use of a low operating saturation temperature (below $0^{\circ}C$.). Hence the saturator is immersed in a thermostat device containing ethylene glycol. Purified air passes through about 70 cm. of copper tubing attached to the inside of the thermostat bath before entering the saturator proper. Dilution is effected by capillaries designed to give a series of ratios of air flow to odour flow with a combined flow of 1 litre/minute (at 5 cm. water pressure difference) at the smelling point. There is minimum turbulence when caps are lifted since odour laden air is flowing through smelling points continuously and exit tubes are located high in the neck of the point. Thus a high recovery rate of concentration is maintained when

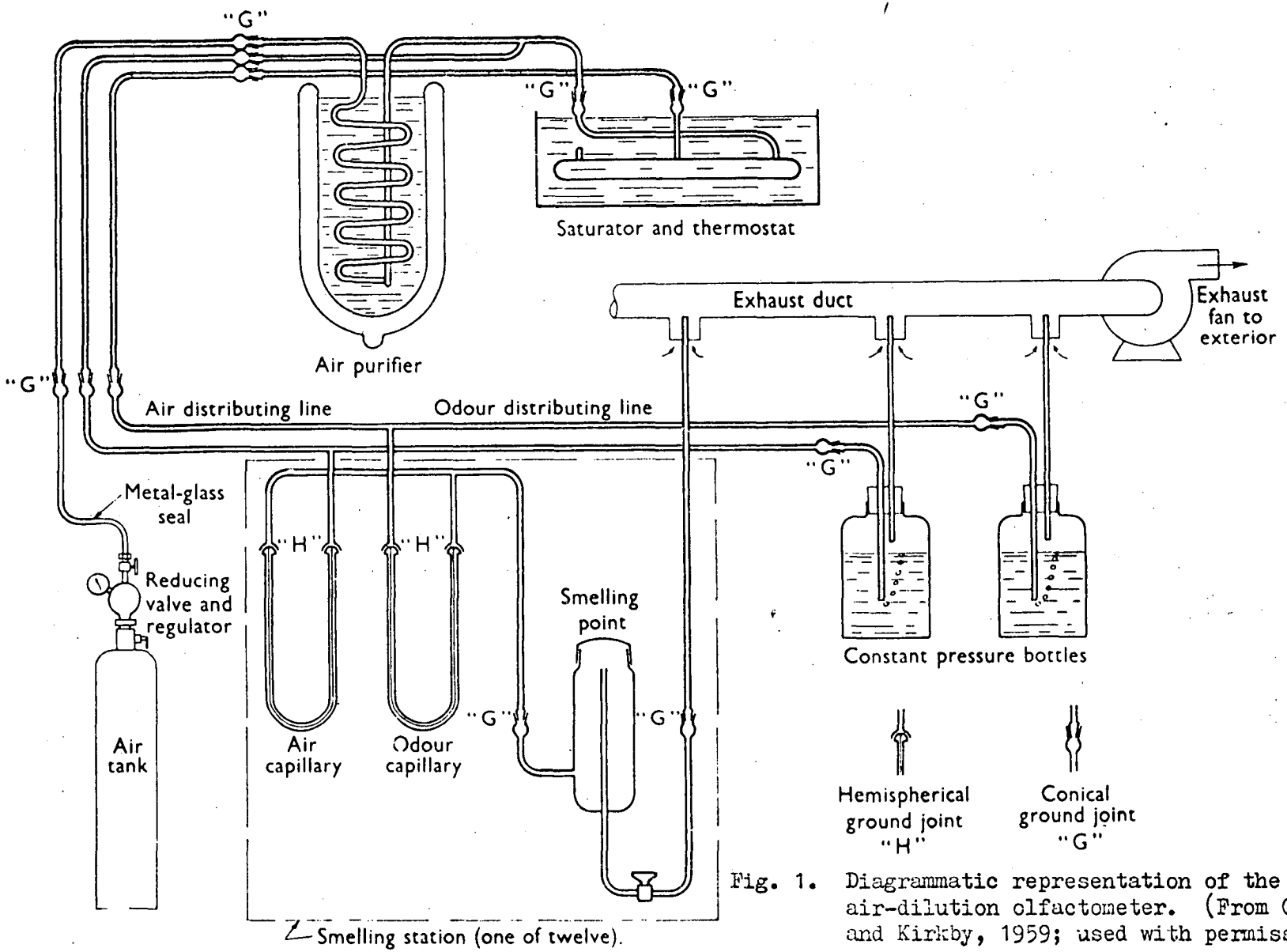


Fig. 1. Diagrammatic representation of the Cheesman air-dilution olfactometer. (From Cheesman and Kirkby, 1959; used with permission).

smelling point caps are replaced at the conclusion of each trial. "Blank"smelling points are set up when the odour capillary is replaced by solid glass tubing and the air capillary delivers 1,000 ml./min. at 5 cm. water pressure.

The prototype apparatus did not allow for adapting odour presentation. In later studies the apparatus has been duplicated so that adaptation effects can be investigated. Only one adapting odour concentration is used during a testing session there being only one pair of air and odour adapting capillaries provided for at any one time. Twelve identical adapting smelling points corresponding to the twelve test smelling points are arranged in a linear array so that subjects move from one pair of adapting and test smelling points to the next.

The whole apparatus is constructed so that it can be dismantled for cleaning purposes. Cleaning by washing in water, soaking in a sulphuric acid-chromate bath, rinsing, steaming, drying in air, and baking at 110°C. is essential when a new odour is introduced into the system or when a lower working saturated vapour is desired.

PRESENTATION OF THE STIMULUS

A consideration of quantitative aspects of the stimulus relates to the presentation techniques which are used. For example, precise stimulus quantification favours artificial stimulus delivery, e.g. injection procedures and the use of nose-pieces, whereas the natural method, i.e. the sniff, does not allow the same degree of control but may be an optimum subject procedure. Two factors, stimulus volume and rate of delivery of the stimulus, have been shown to be determinants of subject's response (Elsberg, Levy and Brewer, 1935b). The "blast injection" and "stream injection" techniques proposed by Elsberg et al. were designed to separate olfactory and trigeminal effects of stimuli

(Elsberg, Levy and Brewer, 1935a) while allowing a high degree of control over dispensation of the stimulus. However the nose-pieces reduced the subject's acuity initially. Cheesman (1955) and Mayne (1953) argue that the subject's judgment is disturbed by the insertion of nose-pieces into the nasal passages and by the conscious attempt to refrain from inspiration while the stimulus is presented. In any case, the experimenter cannot be certain that all odorous molecules will reach the olfactory receptors because of their distance anatomically from the external openings of the olfactory organ and the existence of turbulence in the nasal passages.

The inter-trial period is of paramount importance in olfactory psychophysical experiments. Cheesman (1972) recommends a 30 second interval between presentations based on adaptation curves studies (Köster, 1965). Too frequent presentation results in prolonged adaptation effects over the testing session with variable effects on acuity. Thus accumulation of subject response data is slow compared with vision and audition, and is less reliable since often results of more than one testing session must be used in analysis of results.

CHAPTER 3

CHAPTER 3.

THE CONCEPT OF THRESHOLD

Fechner is generally accepted as having introduced the threshold concept into modern psychophysics. Although he did not preclude the existence of "negative sensations" i.e. responses to subthreshold stimuli, he viewed the threshold as a barrier to be overcome - an idea akin to the "all-or-none" principle of neuronal function.

Since then the sensory threshold concept has come under attack (Corso, 1963) and has been supplanted by a statistical, operational definition. The classical threshold may be defined as that mean value of the stimulus which elicits some arbitrary positive response rate e.g. 50% or 75% within a Gaussian distribution of stimulus values. Threshold theories include High Level Theory (Blackwell, 1953), Low Level Theory including Multi-threshold Theory, (Luce, 1960; 1963 a, b) and Quantal Theory (Von Békésy, 1960). The two-threshold theory proposed by Green approximates Signal Detection Theory and fits data quite adequately (Swets, 1961).

If the observer's (O) task in threshold determination is to attain a 50% positive response rate with as low an intensity of stimulus as possible, then any false positives occuring will be regarded spuriously and will be actively discouraged by the experimenter (E). E will assume that the threshold cannot be exceeded by noise alone and will attribute false positive responses to O's guessing. This will result in O's adopting a high criterion level for positive responses and E's using statistical corrections for O's guesses. Neither operation is likely to give a stable threshold value since O's criterion can change (Swets,

Tanner and Birdsall, 1955) and many "blanks", a number at least equal to that of the stimuli, must be presented to allow for 0 guessing (Steinmetz, Pryor and Stone, 1969). Even then, non-independence of positive response and false-positive rates cannot be assumed (Green and Swets, 1966).

Methods of threshold determination range from the method of adjustment, the method of limits and the method of constant stimuli, in which the order of presentation of stimuli is predetermined, to titration methods such as the stair-case method (Cornsweet, 1962) in which the presentation sequence is dependent on O's responses. Procedural differences, e.g. Yes-No, n-alternative forced choice and second choice, successive response effects (Verplanck, Collier and Cotton, 1952), and warning-stimulus intervals (Treisman and Howarth, 1959), have been shown to contribute to individual threshold variation. As long as the threshold is used as a sensitivity measure without regard for the method by which it was obtained or the various criteria of positive response which O adopts, little hope for consistency of the threshold measure exists. Smith (1961) suggests that the reluctance of psychophysicists, until recently, to pursue new methods of measurement and analysis is a result of their interests being heavily directed towards precision in stimulus quantification.

OLFACTORY THRESHOLDS

The threshold concept has been widely accepted by olfactometrists as a useful tool with which to investigate quantitative relationships between odour stimulus and subject sensitivity. Zwaardemaker (1925) attempted to create subject sensitivity measures based on a population "threshold", a method which is still utilized in clinical audiometry. Although he did not take the physical chemistry of his

presentation device into account, he helped to establish the threshold as a fundamental psychophysical measure in olfaction.

Some odorous substances stimulate both trigeminal and olfactory nerve endings. Thus the proximity of olfactory threshold to trigeminal threshold must be taken into account if pure olfactory response is desired and Moncrieff (1955) actually describes a technique for separating irritant and odorous reactions to such substances.

One of the most frequent criticisms against the use of olfactory thresholds is that of standardization difficulties. With an ever increasing output of data from olfaction laboratories it becomes the more important that stimulus, subject and environmental variables be adequately controlled and allowed for in interpretation of results.

Background odour, temperature and humidity are the environmental factors which have been considered by most experimenters. Other less obvious features such as electrostatic charge density of both subject and surroundings have also received attention (Frey, 1968).

Background odour is most difficult to control without the aid of expensive air-conditioning and filtering apparatus which itself must be odourless. The use of "olfactoria" (Schneider and Wolf, 1955) into which stimuli are introduced approximates real-life situations but inadequate control of stimulus and subject odours limit their reliability. Possibly the most effective way of ensuring a constant, if not non-existent background, is to maintain continuous flow of clean odourless air through the test room.

Woerdeman (1934), using isoamylacetate as stimulus, found that subjects judged the odour stronger at 50°C. than at room temperature, while Mayne (1953) reported no significant effect of temperature or sensitivity for several simple organic compounds within the range 12.5°C. to 35°C. Stone (1963a) suggested that odours entering the

olfactory system attain temperature equilibrium very quickly and that olfactory acuity is not affected by ambient temperature change. This conclusion was reached using acetic acid as stimulus, a compound having both trigeminal and olfactory components and may not be typical for purely olfactory stimuli. More recently Grundvig, Dustman and Beck (1967) measured thresholds for ethyl alcohol at 5-degree intervals from 15°C. to 45°C. and established a linear relationship between the logarithm of the threshold value and temperature. The conflicting evidence on temperature effects may be partly the result of different methods of stimulus presentation: Woerdeman, and Grundvig et al., used blast injection techniques whilst Mayne and Stone employed the "natural sniff" as a means of obtaining receptor stimulation.

Subject variables likely to affect acuity include state of health, smoking habits, age, sex, degree of hunger, and task sophistication. Subjects may be examined medically for nasal obstructions, allergies and asked to indicate illnesses such as sinusitis, cold or influenza.

Mayne (1953) and Pangborn et al. (1964) found no significant differences between thresholds of groups of smokers and non-smokers. This does not negate the importance of smoking habits as possible influences on acuity, especially as the olfactory system is directly involved and nervous and psychological changes in the subject accompany the physical effects of smoking.

Olfactory thresholds increase with the age of the subject (Hinchcliffe, 1962). In keeping with the findings of Welford (1958) that subjects exhibit decreasing perceptual flexibility with age, it is not surprising to note that many olfactory experimenters use young adults as subjects. An interesting approach to age effects involves the use of infants as subjects (Lipsitt, Engen and Kaye, 1963; Murray

and Campbell, 1970). Murray and Campbell showed that sensitivity is dependent on the level of arousal of the infant while Lipsitt attributed threshold changes to temporal factors.

Female subjects are known to exhibit variability in olfactory detection thresholds for certain odours in accordance with bodily chemical changes accompanying the menstrual cycle (Le Magnen, 1952; Köster, 1965). Detection of some odours is at a peak at ovulation and decreases towards the end of the mensis. No such cyclic variation is known to occur in male subjects.

The evidence for hunger and satiety effects on thresholds is equivocal. Goetzl, Abel and Ahokas (1950), Goetzl and Stone (1948) and Guild (1956) suggest that sensitivity rises significantly prior to ingestion and decreases afterwards, whereas the findings of Stone, (1966), Janowitz and Grossman (1949) and Furchgott and Friedman (1960) do not support the notion that minor variations in sensitivity are related to appetite and hunger sensations. Stone and Pryor (1967) report a ten-fold increase in odour sensitivity from morning to evening which was not evident when subjects repeated tasks blind folded. Procedural differences, inadequate control of experimental variables and degrees of rigour of analysis of data may account for some of these disparite results.

Practice effects have been observed in olfaction experiments (Engen, 1960; Friedman, 1960; Semb, 1968) and have been taken into account when determining the threshold by allowing the subject a "settling in" or "warm-up" period at the beginning of an experimental session. Little attention has been given to the subject's expectations, criterion of discrimination or reaction to different pay-off situations. Nor have personality characteristics of the subject been linked with sensitivity much beyond the casual remarks of some experimenters.

The large variations in individual sensitivities that are

observed may be dependent on subject characteristics and methodology (Pangborn, Berg, Roessler and Webb, 1964). Jones (1957) conducted a factor analysis of absolute olfactory thresholds and concluded that individual differences were systematic and not related to stimulus parameters.

The use of group measures or community thresholds has been suggested by Cheesman et al. (Cheesman and Mayne, 1953; Mayne, 1953; Cheesman and Townsend, 1956; Cheesman and Kirkby, 1959; Cheesman, 1972) as a means of randomizing idiosyncratic sources of threshold variations between subjects. While individual differences must be appreciated by the experimenter, the intensive study of relatively few "normal" subjects allows a more detailed examination of subject performance. In the latter case inter-subject effects are minimal or absent and there is no danger of confounding or losing information due to grouping of individual data. The major disadvantage of using the individual threshold (I.T.) is the lengthy procedure required to obtain a reliable threshold - up to 15 times as long as the group threshold determination. Townsend (1956) has compromised by calculating I.T. for each member of a group and combining I.T.s to give a group threshold. Despite its mathematical simplicity, this method suffers from the reduced reliability consequent to the small number of trials used to calculate I.T.

The study of sub-threshold intensities has arisen incidentally in the main. The recent interest in pheromones (Comfort, 1971) and the possibility of low intensity or subliminal communication between animals has emphasised the difficulties encountered in defining an olfactory threshold. Amirov (1954) describes olfactory experiments performed with normal and pathological subjects in which "sub-threshold inhibition" was demonstrated, the extent of inhibitions being dependent on the excitability of the subject's nervous system. The less excitable type

of nervous system displayed most inhibition for a period of up to six minutes after the introduction of the adapting stimulus.

The failure of experimenters using the classical olfactory threshold measure to allow for subject response bias other than by randomizing the variable in group experiments points to the need for a measure of olfactory sensitivity which is independent of response bias and easily defined, yet manageable in terms of time taken to achieve it.

CHAPTER 4

CHAPTER 4.

THE THEORY OF SIGNAL DETECTABILITY AND ITS APPLICATION TO OLFACTOMETRY

The classical threshold concept has dominated olfactory sensitivity measurement for over one hundred years. Psychophysicists have been content to use percentage positive response within a stable false positive rate as a measure of sensitivity, not allowing for subject variables such as degree of motivation, expectations or response bias. Some experimenters have noted that variation in subject instructions can produce conflicting results (Fernberger, 1931), but an appreciation of subject attitudes is just beginning to develop among olfactometrists.

The theory of signal detectability allows quantitative consideration of hitherto unmeasurable aspects of subject performance. Originally put forward as a theory appropriate for the use of communication engineers (Peterson, Birdsall and Fox, 1954) it has recently been wedded to statistical decision theory and applied to the human observer (O) (Tanner and Swets, 1954). Instead of stimulus effect being considered as invariant and a subject who exceeds an arbitrary false positive rate as being unreliable, the observer is seen as attempting to discriminate a signal from noise inherent in the system in which he operates. Noise may be the random neural activity within O's central nervous system and/or either constant or varying physical environmental noise. O will be forced to take risks in order to maximize his gains taking into account the a priori probability of signal occurence and the costs in responding a certain way. He will

adopt a criterion for deciding whether a signal is present or not on any trial. Signals which reach criterion level or surpass it will be designated "signal present" while those that fail to reach the criterion will be "signal absent" responses. There is the possibility that random fluctuations in noise may exceed the criterion and be interpreted as a signal.

Since noise varies randomly within O's nervous system and signals are superimposed upon it, overlapping Gaussian distributions of noise (N) and signal plus noise (S + N) can be thought of as being established centrally. This is shown in Fig. 2 where the abscissae represent either a "decision axis" or degree of neural activity in the decision making apparatus. The means of the distributions, $\overline{X}_N$ and $\overline{X}_{S+N}$, are separated by a distance d'which is an indicator of O's sensitivity. The greater the overlap of the two distributions, the smaller the value of d' and the less sensitive is O to a given stimulus. In the limiting case of coincidence of distributions O is unable to distinguish between signal and noise i.e. d' = 0 and the "hit" rate and "false alarm" rates become equal. The criterion C_1, set by O, is assumed to be constant under a given set of experimental conditions. It can be seen that C_1 cuts across both S and S + N distributions thus allowing for a small positive response rate. If the ordinates at C_1 are Y_{S+N} and Y_N for signal and noise distributions respectively, then the likelihood ratio Y_{S+N}/Y_N (called β) provides a measure of O's tendency to use hits or false alarms as responses i.e. his response bias. β will become unity when the criterion is set at the inter-section of the two distributions (i.e. O has no bias) and less than unity when set well within the noise distribution (bias towards reporting "signal absent").

Thus the theory provides for two independent measures: one of

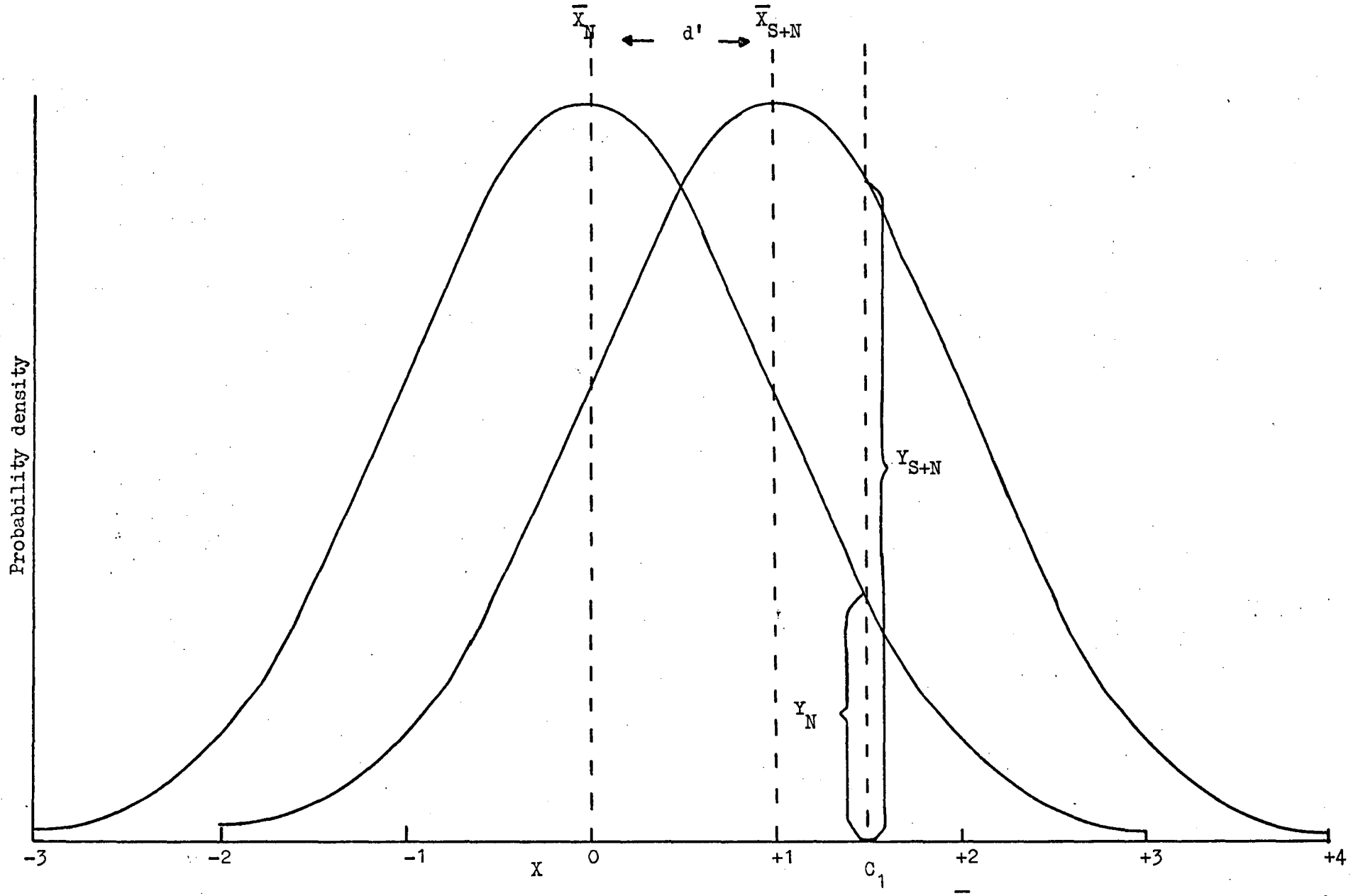


Fig. 2. Distributions of signal and noise. The mean of the noise distribution, $\bar{X}_N$, is set at zero and that of the signal distribution, $\bar{X}_{S+N}$, at a distance of one standard deviation from $\bar{X}_N$. C_1 represents a criterion point adopted by O.

sensitivity, the other of bias. This is a considerable advance on the threshold theories where bias estimates are not considered other than forcing O to adopt a high criterion and forming "signal absent" responses.

PRACTICAL IMPLEMENTATION OF THE THEORY OF SIGNAL DETECTABILITY

A priori probabilities of signal and noise occurence are usually set at 0.50 each, except in those experiments where probabilty is used as an independent variable. Four subject responses with associated conditional probabilities are possible - (i) hits i.e. correct detections (ii) misses, (iii) false alarms (iv) correct negative responses. Hit rate is designated by the symbols P (S/s), the conditional probability of a signal being interpreted as a signal by O, and false alarm rate by P (S/n).

The criterion of O's response can be manipulated by the experimenter (E) so that values of P (S/s) and P (S/n) can be obtained for a particular response criterion. P (S/s) and P (S/n) are determined for at least five criterion points and a receiver operating characteristic curve (ROC) is traced out by plotting P (S/s) against P (S/n) as shown in Fig. 3. The proportion of area under the ROC curve can be calculated and P (A), a non-parametric measure of sensitivity determined. Since d' can only be used when S and S+N distributions are Gaussian and of equal variance, P (A) and several other measures e.g. de' andΔm are used in cases of non-Gaussian and unequal variance situations. A double-probability plot of P (S/s) against P (S/n) yields a straight line graph from which d', d_e' orΔm and the ratio of standard deviations of signal to noise distributions can be determined.

DETECTION METHODS AND THEIR SUITABILITY FOR USE IN OLFACTION EXPERIMENTS

In olfaction experiments compromises must be made between the

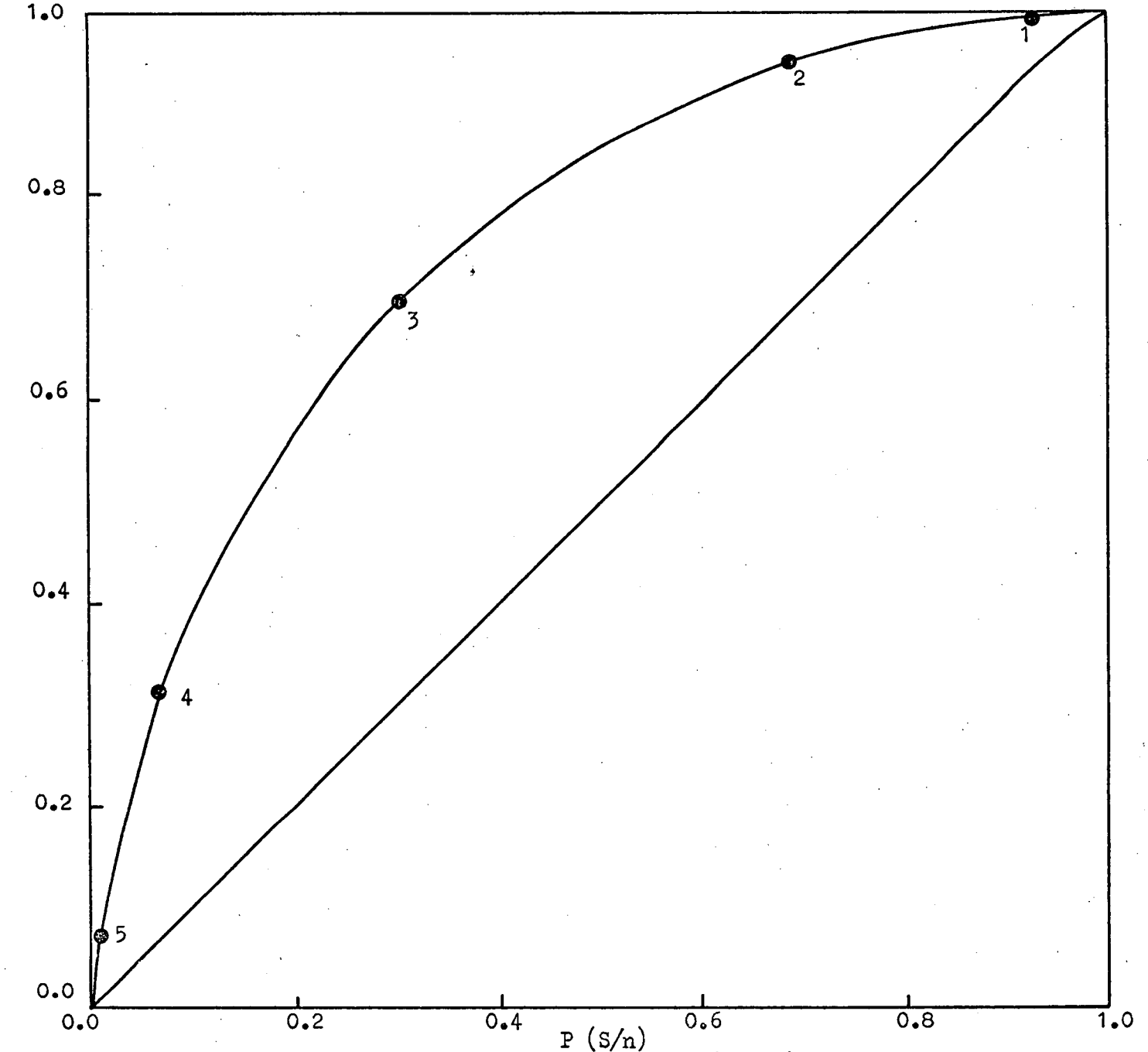


Fig. 3. ROC curve based on five criterion points (1 - 5).

power of a derived statistic and the time required to obtain it. The inter-trial period required for complete recovery of the olfactory system has been shown to be of the order of 0.5 minutes at least (Köster, 1965). Cheesman (1972) advocates the use of even longer periods to be certain of recovery. This imposes severe restrictions on the number of trials that can be undergone by O in one session. Fatigue, boredom and attention effects can seriously interfere with O's performance if sessions are prolonged. Thus while it is possible to maintain high rates of auditory stimulus presentation per three hour sessions, no more than several hundred trials are possible with olfactory stimuli. E must decide whether to combine results from different sessions or whether to settle for a less powerful measure such as P(A). The three principal methods used in Signal Detectability are now discussed.

THE SINGLE-INTERVAL YES-NO PROCEDURE

O is limited to "yes" and "no" responses only. Decision criteria may be changed by either varying the a priori probability of signal occurence, varying the pay-off rewards and costs, or requiring O to adopt a "strict", "medium" or "lax" criterion. A minimum of 500 trials per point on the ROC curve is recommended (Green and Swets, 1966). If five points are sufficient to yield a reliable curve then 2500 trials are necessary to give values of d' and β. It is impossible for O to undergo such a large number of trials in one session when olfactory stimuli are used.

THE RATING PROCEDURE

This approach is based on the assumption that O can deal with several independent criteria simultaneously. O rates his confidence

of signal presence or absence by using categories ranging from utmost certainty of signal presence to utmost certainty of signal absence. Up to six categories are generally used although an infinite number of categories have been used in at least one experiment incorporating the use of a sliding marker on a rule (Watson, Rilling and Bourbon, 1964). The raw data are compressed to yield hit and false alarm rates for a number of criteria equal to one less than the number of categories. The disadvantage of this method is that the points on the ROC curve are not independent as in the yes-no procedure. However, only 500 trials are needed to attain reliability if six categories are used, and this is a more attractive proposition for olfactometrists.

In view of the considerably smaller number of trials required with the rating method as against the yes-no method, various researchers have attempted to compare the two procedures in similar experimental situations. Egan, Schulman and Greenberg (1959) and Emmerich (1968) found that both methods produced similar ROC curves with auditory signals, whereas Markowitz and Swets (1967) consistently reported ROC curve slopes of less than unity with the rating procedure. However, the fact that Egan and Emmerich varied a priori probability of signal occurence while Markowitz varied subject instruction may partly account for the disparate results.

THE TWO-INTERVAL FORCED-CHOICED PROCEDURE

The signal occurs in either of two temporal intervals occuring consecutively. It is an economical method and tends to minimize bias since signals are assigned randomly to the two intervals. The long recovery period in olfaction limits its usefulness.

Threshold theory has been criticised for its neglect of subject

bias characteristics (Green and Swets, 1966; McNicol, 1972) yet Treisman and Watts (1966) have established a statistical decision model for absolute and difference thresholds obtained by the method of constant stimuli. Threshold measures, e.g. the Crozier ratio, are shown to be indicative of bias and d' estimates predicted from threshold data are in line with those obtained using signal detectability techniques. That common features of both theories can be incorporated in a single theory offers the olfactometrist some limited comparison between the abundance of threshold determinations present in the literature and the relatively few but growing number of signal detectability experiments.

Physiological evidence supporting the statistical decision theory approach to sensitivity measurement in humans is given by Bauer et al. (1972). Unanaesthetized cats with electrodes implanted in their brainstem auditory nuclei were subjected to auditory stimuli which were interpreted according to a statistical decision model programmed into a digital computor. Psychometric functions were very similar to those of human O's using identical stimuli.

Olfactometrists have been slow to make use of signal detectability techniques. Semb (1968) stated that "sensory coding in the olfactory system had not been examined within the context of detection theory" until the appearance of his paper. This could be the result of the tedious nature of olfactory experiments compared to the ease of administration of visual and auditory experimentation. The theory of signal detectability, while providing a more "pure" measure of olfactory sensitivity, is tied to a relatively large number of trials in its implementation compared to threshold theory. Thus the olfactometrist is faced with the task of developing a procedure based on the signal detectability paradigm, which is more economical of time yet is no less powerful than that used in visual and auditory sensitivity measurement.

CHAPTER 5

CHAPTER 5.

OLFACTORY ADAPTATION AND ODOUR CLASSIFICATION

Olfactory adaptation is well represented in psychological literature, the experimental study of the phenomenon dating back to the latter half of the nineteenth century (Aronsohn 1886; Zwaardemaker, 1895). Adaptation occurs when an observer (O) experiences a reduction of sensitivity to a stimulus either as a result of continuous exposure to that stimulus or by repeated contact with the same or different stimulus superimposed on the initial stimulus. Thus it is possible to distinguish between temporal and intensity aspects of adaptation although temporal aspects must, of necessity, be considered when intensity effects of adapting stimuli are being studied.

Adaptation curves (Ekman, Berglund, Berglund and Lindvall, 1967) and recovery curves (Stuiver, 1958) of simple odourous compounds show an exponential change in sensitivity with time. However further studies (Cain and Engen, 1969; Berglund, Berglund, Engen and Lindvall, 1971) cast doubt on this generally accepted notion which Berglund suggests is an artifactual result arising from the experimenter's (E) inadequate methods of instruction to O. Possibly the differences of opinion arise from the discontinuous nature of the olfactory receptive process in that stimulus input is separated by regular intervals of expiration. During this time adaptation effects will very quickly reach a maximum and dissipate slowly thereby reducing cumulative effects.

The intensity of the adapting stimulus and its effect on the sensitivity for the adaptive (test) stimulus may be studied under

two conditions viz. co-adaptation when adapting and test stimuli are identical and cross-adaptation when they are different. There is abundant evidence to show that co-adaptation processes have the more marked effect on sensitivity. Cross-adaptation is less severe and may even facilitate sensitivity (Engen and Bosack, 1969; Corbit, 1969; Corbit and Engen, 1971). Cross-facilitation has received limited attention as yet and is in need of further experimental investigation.

ADAPTATION MEASUREMENT

Adaptation studies may be divided into two classes - those in which stimuli at near threshold concentration have been used and those employing suprathreshold stimuli.

Cheesman, Mayne and Townsend (Cheesman and Mayne, 1953; Mayne, 1953; Cheesman and Townsend, 1956; Townsend, 1956), using the sniff-bottle technique and a wide range of adapting stimuli concentrations have shown that the group threshold increases in a systematic manner as the adapting stimulus concentration is increased. The results of later experiments (Cheesman, 1972) incorporating air-dilution techniques of stimulus presentation lack the consistency of the earlier ones probably because of changing experimental conditions over the nine-year test period. Moncrieff (1956, 1959) repeated the Cheesman-type investigation and found support for Cheesman's proposition that a plot of the logarithm of the adaptive odour threshold concentration against the logarithm of adapting odour concentration yields a straight line. (Moncrieff used the ordinate log. $\frac{C1}{C2}$ where C1 = threshold after adaptation and C2 = threshold prior to adaptation. Thresholds were based on 45 trials only). Cheesman points out that this relation holds only for a limited range of adapting odour concentration, probably up to 15 times adaptive odour threshold concentration.

Ekman et al. (1967) criticise the threshold experiments arguing that processes of adaptation at supraliminal intensities cannot be inferred from such studies. As an alternative, scaling methods, including direct scaling procedures, ratio estimation and magnitude estimation have been used to examine the intensity-sensitivity relation of suprathreshold odours (Engen, 1964; Gregson, Mitchell, Simmonds and Wells, 1969; Berglund, Berglund, Engen and Ekman, 1972; Cain, 1971). The findings support the power law of Reese and Stevens (1960), the exponent of the function being less than unity. The effect of adaptation on the value of n has been determined when adapting and adaptive odour concentrations are subjectively equal. Pryor, Steinmetz and Stone (1970) and Cain and Engen (1969) report an increase in the value of n under adaptation conditions while Mitchell and McBride (1971) report a decrease. The use of different scaling techniques and the limited number of odours investigated does not allow for generalization, but a combination of scaling and threshold approaches has been put forward as suitable to the study of adaptation (Pryor, Steinmetz and Stone, 1970).

The application of signal detectability theory to adaptation has only recently been tested (Corbit, 1969; Corbit and Engen, 1971; Berglund, Berglund, Engen and Lindvall, 1971). Berglund et al. developed a model of adaptation in which duration effects result in an equal movement of S and S + N distributions along the excitation axis thus maintaining a constant hit rate and an alternative mechanism in which the variance of both distributions becomes unequal operates during adaptation. Corbit claims that intersubject variability is less when detection methods are used. Yes-No procedures have been used to determine d', the sensitivity index, and the proportion of false alarms was taken as a measure of O's bias. As yet no studies have been recorded in which rating procedures were used.

The relative contribution of peripheral and central factors to olfactory adaptation has been clarified somewhat by electrophysiological measurement. Although Ottoson (1956) has shown that peripheral adaptation can occur in the frog, Adrian (1954) places emphasis on the disruption and subsequent restoration of the underlying rhythmic electrical activity in the olfactory bulb. Elsberg (1936) viewed adaptation as a central phenomenon resulting from the blockage of neural pathways from perception areas to discrimination areas of the brain. Köster (1965) and Moncrieff (1956) believe that most experiments on adaptation are measuring central rather than peripheral (or receptor) adaptation. If adaptation is primarily central in origin it may provide an indirect means of investigating odour discrimination and hence odour classification.

ODOUR CLASSIFICATION

Many attempts have been made to classify odours on the basis of molecular characteristics such as size and shape of the molecule, adsorption properties, absorption and emission spectra and solubility. All have lacked consistency, which has prompted Pfaffman to conclude that "no single stimulus-dimension is likely to account for the complex olfactory system" (Pfaffman, 1951, 1956).

The most satisfactory classification, at the operational level, is the stereochemical theory of Amoore (1952, 1963, 1964) in which seven "primary" odours based on molecular size and shape are proposed. Implicit in the theory is the notion of specific types of receptor capable of accommodating a "primary" odour.

An alternative approach to classification involves the use of psychophysical measures such as scaling of odour quality likeness and adaptation effects of one odour on another. The latter was proposed by Zwaardemaker (1895) on the assumption that similar odours will have

greater adapting effects on each other than non-similar ones. Cheesman and Mayne (1953) developed this concept so that a derived measure viz. the slope of a log-log plot of threshold elevation against adapting stimulus concentration, was used as a "degree of community" between the four odours investigated. Co-adaptation conditions yielded slopes of +0.7 whereas cross-adaptation slopes were always less than +0.7 and were not symmetrical for pairs of odours. Townsend (1956) repeated and reanalysed some of the earlier work and found that the number of subjects used to calculate a group threshold and the position of the threshold in the series of presentation stimulus were important determinants of the slopes. Facilitatory effects of adaptation have not been considered by Cheesman and his co-workers, but if facilitation is established as fact consideration will have to be given to the meaning of negative slopes in the Cheesman hypothesis.

Inter-subject and intra-subject threshold variation tends to reduce the reliability of derived measures and Amoore (1972) views adaptation measurement as being supplementary to specific anosmia studies in classification research. He claims that adaptation alone cannot identify primary odours but can lend support to similarity scaling and confusion methods. Engen (1963) comes to a similar conclusion supported by results of a factor analysis of odours likeness. It appears that adaptation is a generally less powerful method than similarity scaling methods. But it is highly selective.

Adaptation measurement, as a specific example of olfactory sensitivity measurement, is worthy of investigation using the signal detectability paradigm. This is because any odour classification which is based on the mutual adaptation effects of one odour on another must be more valid if subject sensitivity is separated from subject bias. The present study includes the application of signal detectability.

techniques to olfactory co-adaptation where changes in sensitivity are most marked.

CHAPTER 6

CHAPTER 6.

THE AIM AND METHOD OF THE PRESENT STUDY

The aim of the experimental programme was to compare the applicability of threshold and signal detectability techniques to the study of olfactory acuity and adaptation within an established framework of operations viz. that adopted by Cheesman and Mayne (1953). It was hoped to determine whether the allowance for subject response bias in the signal detectability paradigm was relevant to the Cheesman approach since ultimately the building up of a classificatory system of odours based on olfactory adaptation measurement could be affected if subject response bias was a significant factor. The classification matrix developed by Cheesman and Mayne (1953), extended by Townsend (1956) and later revised by Cheesman (1972), is based on mutual adaptation effects of one compound on another with minimum reference to the subject's decision-making characteristics except where related to stimulus intensity e.g. Mayne (1953) considered that subliminal adapting odour concentrations were inappropriate since the subject had a standard "absence" of odour with which to compare the test stimulus whereas at supraliminal concentrations he did not.

It was planned to extend the concentration range of adapting stimuli beyond the limits set by Cheesman and Mayne to incorporate concentrations up to forty times absolute threshold. This seemed desirable in view of the low upper limit of about ten to fifteen times threshold used by Cheesman and Mayne (1953). The choice of test stimulus concentration is rather arbitrary when signal detectability methods are used to study olfactory adaptation (Berglund, Berglund, Engen

and Lindvall, 1971). A concentration at or near threshold is used most often. It seemed that valuable information would be gained if the range of test stimuli were extended either side of threshold, rather than relying on an arbitrary test concentration which could yield unique results.

The experiments undertaken by Cheesman, Mayne and Townsend involved many subjects undergoing a limited number of tests on several odours. The proposed study was concerned with the intensive testing of a few subjects with one odour stimulus (isopropyl alcohol). It was anticipated that intra-subject variability of response might be more readily examined by this means than by employing group measures of sensitivity. Furthermore, a comparison of psychophysical methods would be set within the same individual.

The number of trials required to yield a sensitivity measure that is independent of observer bias is approximately twice that of the threshold determination as used by Mayne. Whereas Mayne used a mean of twenty-one subjects undergoing twelve trials each, it is suggested that the reliability of the measure d' is not sufficient below five hundred trials (250 S, 250 N) for adequate investigation of sensitivity (Green and Swets, 1966). This raised the question as to whether the experimenter should aim to minimize the number of sessions in which a particular stimulus concentration was used or whether he should include the maximum number of stimuli available in a relatively large number of sessions. The latter has the advantage of uniform conditions operating for every stimulus concentration over at least one session while the former enables non-parametric sensitivity measures e.g. $2 \arcsin \sqrt{P(A)}$ to be calculated under one set of conditions. However this measure is open to question when mathematical stimulus-intensity relationships are sought. (McNicol, 1972).

In studies of vision the use of more than one stimulus intensity within a single session has been shown to be a valid procedure when results are analysed by signal detection methods (Emmerich, 1968). Thus if multiple test stimulus concentrations were incorporated into olfactory sessions and several adapting stimulus concentrations were used over sessions it should be possible to (a) trace the variation of a sensitivity index with test stimulus concentration for a given adapting stimulus concentration, and (b) trace this relationship over several different adapting concentrations extracting some index of adaptability e.g. the index-test concentration relationship could be linear for a given adapting concentration as it is when adapting concentration is zero (Semb, 1968). The gradient of the plot could be characteristic of the test stimulus compound and could be similar for all adapting concentrations or alternatively the plotting of the gradient against adapting concentration could give a measure of the degree of "communality" between test and adapting stimuli which would be independent of observer bias.

In summary, the aim of the present study was to investigate changes in sensitivity using a small number of subjects in an intensive testing programme under conditions of co-adaptation and non-adaptation. A direct comparison was to be made between variants of standard signal detectability technique and threshold procedures.

OUTLINE OF PROGRAMME

Experiment I. Absolute threshold determination using the method of constant stimuli with consideration of practice and learning effects. This was attempted first so that subjects could become acquainted with a simple form of response before moving onto more complex responses. The variation of

threshold over sessions was to serve as a guide to the extent of chance fluctuations in threshold in Experiment IIIa.

Experiment II. Use of signal detectability rating techniques to investigate concentration/sensitivity relationships. The rating technique was preferred to the yes-no technique in view of the economy of time of the former method. The results of using multiple test stimulus concentrations in sessions were to be compared with results in single-test sessions.

Experiment III. The variation of (a) absolute threshold, and (b) signal detectability sensitivity measures during olfactory co-adaptation. The results of Experiment IIIa were to be compared with those obtained in group threshold experiments conducted by Mayne (1953) and Cheesman (1972). The feasibility of using a signal detectability index as a measure of the extent of co-adaptation was to be considered in the light of the results of Experiment IIIb.

Each experiment was to be performed using both the sniff-bottle technique and the air-dilution technique of stimulus presentation.

METHOD

SUBJECTS

Two panels (X and Y) of paid subjects were used, panel X working with the sniff-bottle technique and panel Y with the air-dilution form of presentation. Panel X consisted of three males, Subjects A, B and C aged 19, 20 and 21 years respectively; panel Y consisted of one female, Subject D, aged 20 years and three males,

Subjects E, F and G, aged 24, 21 and 22 years respectively. All were undergraduate students of the University of Tasmania. Subject F was the only smoker, smoking about fifteen cigarettes per day.

Male subjects were preferred to female subjects because of the variability of female responses to some odorous stimuli with the menstrual cycle (Koster, 1965). Subjects were medically examined to ensure freedom from nasal obstruction and allergies.

APPARATUS

The Sniff-Bottle

Twelve 125 ml. dark glass, wide-mouthed, glass stoppered bottles were used to hold aqueous solutions of the stimulus. These were mounted on a 101 cm. diameter rotatable table which was set up on a bench adjacent to the wall dividing test room from laboratory. The centre point of the table was located so that the table overlapped through openings into the test room allowing smelling stations to be presented individually to S seated in the test room. The openings were boxed in and a lift-up lid provided on the test room side so that the smelling stations could be chosen by the experimenter (E) and presented to S at the appropriate time. Fig. 4 shows the table mounted in the laboratory. The bottle M containing the adapting odour was originally attached to the bench in front of S but was later removed so that S could pick up the bottle during testing, this being a less awkward procedure.

The Air-Dilution Olfactometer

The air-dilution olfactometer designed by Cheesman (Cheesman and Kirkby, 1959; Cheesman, 1972) was modified for testing of individual subjects by incorporating a circular array of movable smelling points rather than a stationary linear arrangement (Fig. 5). Twelve

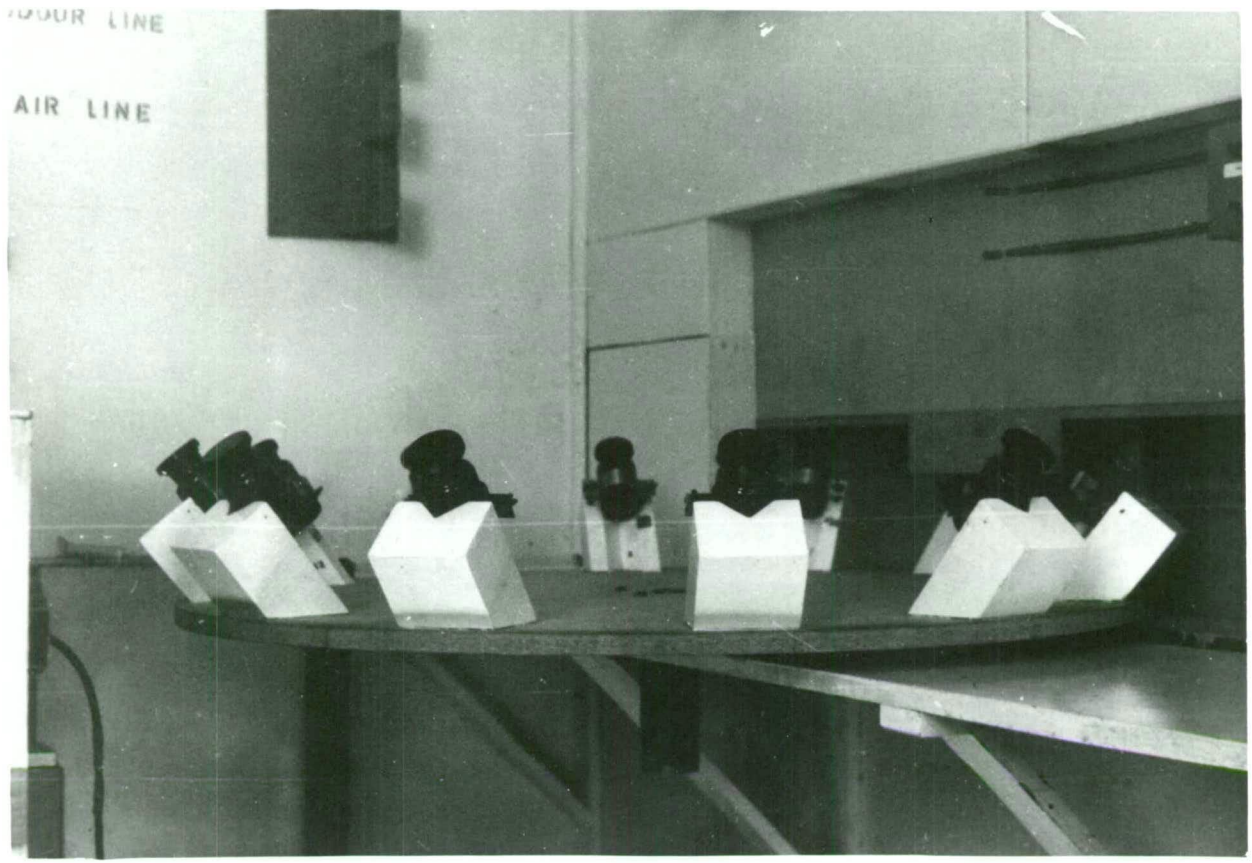


Fig. 4. Rotatable table and smelling stations used in the sniff-bottle experiments.

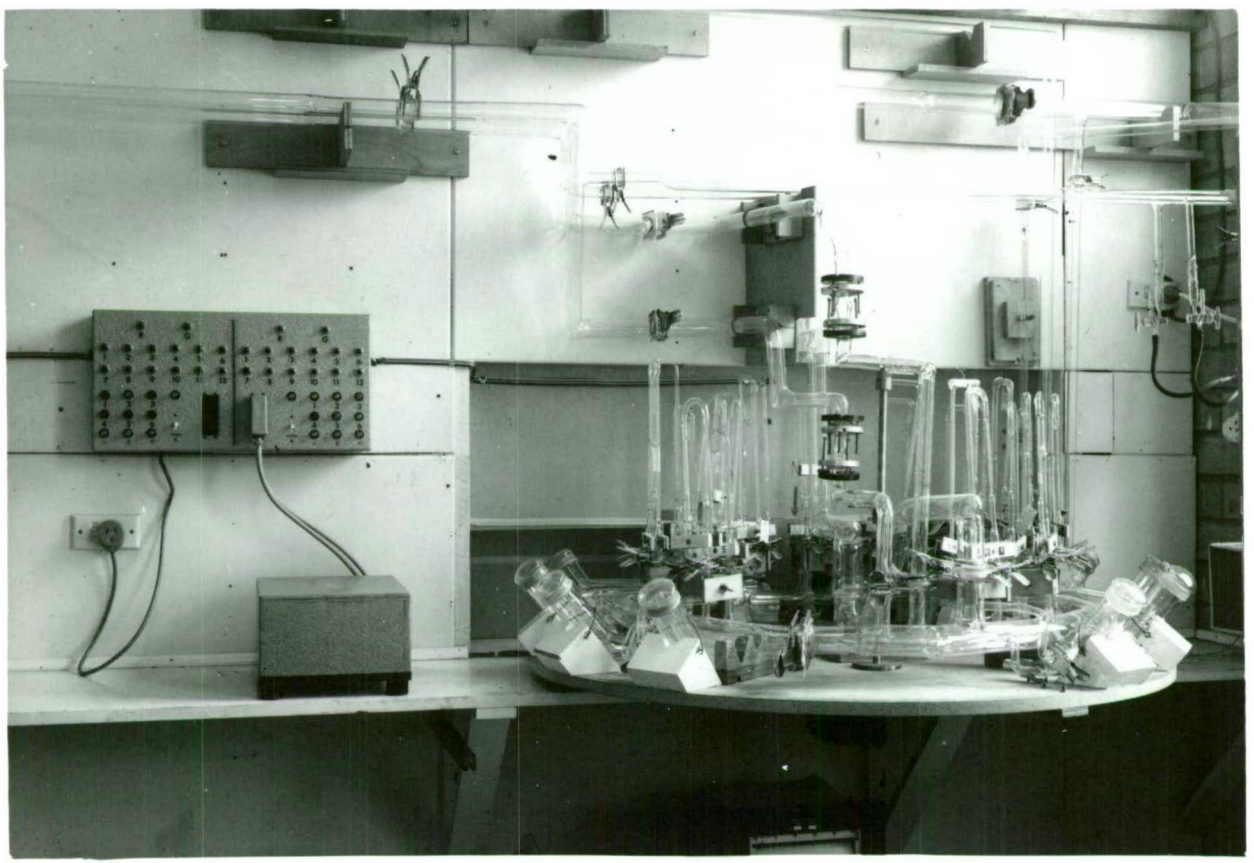


Fig. 5. The Cheesman air-dilution olfactometer modified for individual olfactory sensitivity measurement.

smelling points and their associated circular air, odour and exhaust lines were mounted on the rotatable table described previously. Rotation was achieved by spherical ground-glass joints as used in all the apparatus with the added protection of minimum tension clamps at the points of rotation.

The air purifier, saturator and thermostat devices were those used in the previous group threshold studies. Capillary tubes, although compacted, followed the same dilution ratios as used by Cheesman (Table 1) and were calibrated at a pressure difference of 5 cm. head of water. A fixed adapting smelling point was positioned to one side of the test point opening so that S could manipulate its cap with his left hand and the test point cap with his right hand (Fig. 6). Provision was made for twelve adapting smelling points of varying concentrations to be used in conjunction with the twelve movable test points.

A second table and signaling device was set up next to the first to enable two subjects to be tested at once. Subjects were separated by a screen.

Adapting line capillary tubes were identical to those used in previous experiments (Cheesman, 1972). The dilution ratios used appear in Table 2 and the arrangement of the capillaries is shown in Fig. 7. Allowance had to be made for the reduced number of adapting smelling points and a "bleed" at the exhaust end of the apparatus was required to ensure standard flow rate of 1,000 ml./min. through these points.

Communication between E and S was effected by a system of buttons and coloured lamps in all experiments thus avoiding direct S-E interaction. S's display board consisted of an amber warning light of 0.5 seconds duration, a red light and a green light; a set

TABLE 1.

Dilution ratios of capillary tubes used to supply test smelling points.

Designation	Rate of flow in l./min. at 5 cm. pressure difference	Dilution Ratio
640	0.640	1 : 1.60
640A	0.360	
320	0.320	1 : 3.10
320A	0.680	
160	0.160	1 : 6.25
160A	0.840	
80	0.080	1 : 12.5
80A	0.920	
40	0.040	1 : 25.0
40A	0.960	
20	0.020	1 : 50.0
20A	0.980	
10	0.010	1 : 100
10A	0.990	
5	0.005	1 : 200
5A	0.995	
2.5	0.0025	1 : 400
2.5A	0.9975	
1,000Q	1.000	
1,000R	1.000	"blanks"
1,000S	1.000	

Capillaries were paired in operation, the odour-laden air capillary (designated by numbers only) and pure air capillary (designated A) combining to give a total flow rate of 1,000 ml./min. to each test smelling point.

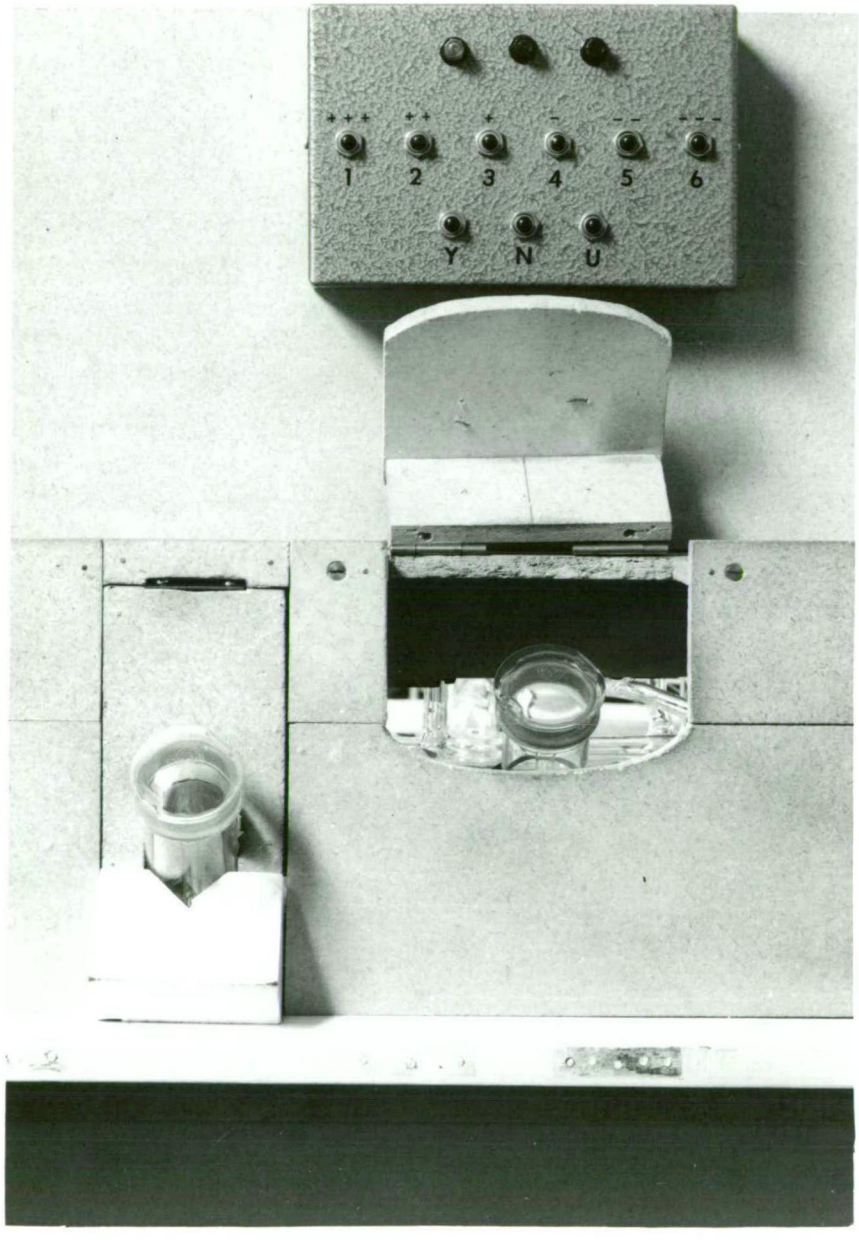


Fig. 6. Subject apparatus: adapting smelling point (left) and test smelling point (right) with subject's signaling device immediately above opening.

TABLE 2.

Dilution ratios of capillary tubes used to supply adapting smelling points

Designation A = pure air FO = odour-laden air	Rate of flow in l./min. at 5 cm. pressure difference	Theoretical dilution ratio	Actual dilution ratio
*FA 1200	12.00	-	-
FO ZERO	0.00	"blank"	"blank"
FO 150	0.150	1 : 80	1 : 104.3
FO 240	0.240	1 : 50	1 : 75.0
FO 380	0.380	1 : 31.6	1 : 42.1
FO 545	0.545	1 : 22.0	1 : 25.0
FO 900	0.900	1 : 13.3	1 : 16.7

* Although capillary FA was capable of delivering 12.00 l./min. at 5 cm. pressure difference, the combined flow rate was adjusted to 12.00 l./min. by use of a rotameter flow guage thus giving rise to the non-ideal ratios in column 4.

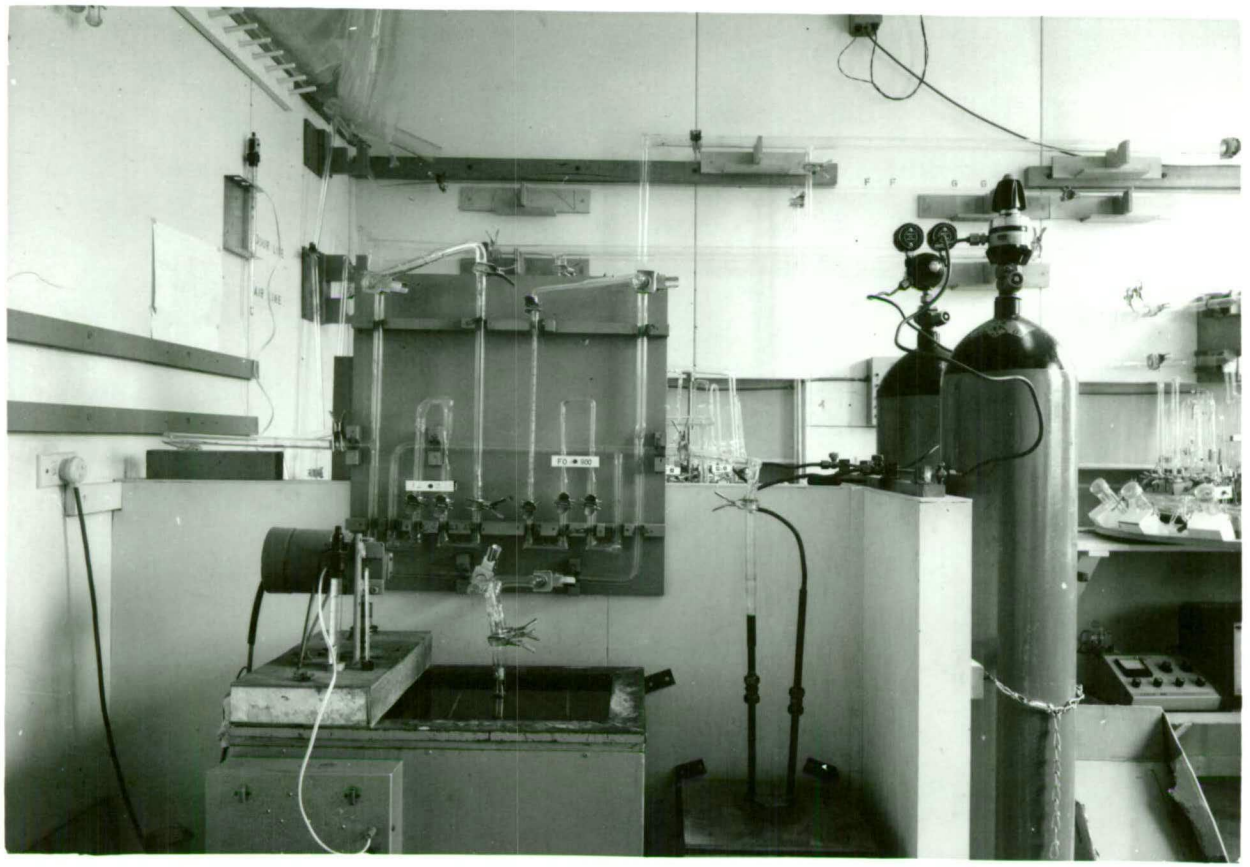


Fig. 7. Adapting odour line showing purifier and saturator in foreground and accompanying fixed capillary tubes.

of buttons labelled Y, N and U; and a second set of buttons labelled 1 through 6. E's display board contained buttons labelled 1 through 12 which were used to illuminate S's amber warning light; buttons R and G which illuminated S's red and green light respectively; a red light a green light and an amber light which corresponded to S's buttons N, Y and U and a set of six clear lights labelled 1 through 6 corresponded to S's set of buttons of the same nomenclature.

S indicated his responses to E by pressing either button for a positive response, button N for a negative response or button U for an uncertain response, which illuminated the green light, the red light or the amber light respectively on E's display board.

E could inform S of the presence or absence of the stimulus by pressing either button G for stimulus presence or button R for stimulus absence, which illuminated the green light or the red light respectively on S's display board. The six buttons numbered 1 to 6 and E's corresponding clear lights were used when rating techniques were employed.

E's choice of smelling point and S's corresponding response were recorded automatically by means of a moving roll of photographic paper and a row of microlamps contained in a light-proof box used in conjunction with the signaling system.

An air lock, to prevent stray odours reaching S, was produced by building a wooden enclosure with a second door immediately inside the test room entrance. Rubber seals were attached to the bottom of each door. Air was circulated in the test room by the use of inlet and exhaust fans. Care was taken to ensure that air pressure in the test room always exceeded that of the laboratory and preparation rooms so that the test room was as free as possible from foreign odours. Temperature in the test room was controlled by E noting room temperature

every thirty minutes and switching on a wall heater if necessary to maintain an ambient temperature of 18°C.

THE STIMULUS

Isopropyl Alcohol, CH_3 CH(OH) CH_3, was chosen as test stimulus for its hedonically neutral properties and low trigeminal component. It has been described by Moncrieff (1944) as having a slightly spiritous odour and a markedly lower olfactory threshold than the trigeminal or irritant threshold. Thus there is little possiblity of subjects being offended by the odour at the dilutions used for testing purposes and there should be no confusion between olfactory and trigeminal thresholds.

A fresh supply of isopropyl alcohol of sufficient quantity for the entire programme, of Analytical Reagent standard of purity (Appendix I), was obtained initially and stored in a set of dark glass stoppered reagent bottles so that at no time was there an air space of more than ten per cent of total volume above the liquid surface. In this way reasonable standards of purity were maintained over the rather protracted testing period.

PREPARATION OF THE STIMULUS

Sniff-Bottle Technique

Since contamination is a very severe threat to quantitative work in olfaction, the cleaning of test bottles was given careful consideration. The following steps were taken:

(i) Washing with much cold tap water and brushing the necks with a stiff, coarse-fibred bottle brush.

(ii) Immersion in a sulphuric acid-chromate bath for fifteen minutes.

(iii) Rinsing in much cold tap water.

(iv) Draining, rinsing and filling with distilled water and replacing cap.

(v) Immersion in distilled water in a sterilizer. Boiling for five to six hours.

(vi) Drying for three hours at 110°C. in a drying oven.

A fresh set of bottles was brought into operation after every third testing session except where ageing effects of the stimulus material were investigated.

A pipette technique was developed for solution preparation. In Experiments I and III (a) a standard solution λ_1, of either 16.0 x 10^{-2}M or 8.0 x 10^{-2}M concentration was successively diluted with boiled tap water to give a binary series of nine solution concentrations. In addition three "blanks" consisting of boiled tap water only were added to the series to give a ratio of 0.75 : 0.25 stimuli to "blanks". In Experiments II and III (b) the ratio was 0.50 : 0.50, six smelling points containing solutions of equal strength while the remainder contained boiled tap water only. Boiled tap water was used as diluent in preference to distilled water which has a "flat" smell. "Odourless" organic compounds such as diethyl phthalate were considered unsuitable since it is questionable whether they are truly odourless. Tap water was expected to resemble the chemical composition of the olfactory membrane to an extent thus making it potentially less odourous than other diluents.

Air Dilution Technique

450 ml. of undiluted isopropyl alcohol was placed in the test and adapting line saturators and trial runs were undertaken to establish a working temperature such that the range of stimulus

concentrations presented to subjects was within reasonable limits of subject sensitivity i.e. subthreshold and very high concentrations were avoided. This was not always possible when two subjects of markedly different olfactory acuity were tested simultaneously. However subjects of similar olfactory sensitivity were grouped together for testing as often as time table arrangements would allow.

E monitored flow rates continuously by use of "rotameter" guages so that the standard flow rate (1,000 ml./min.) was maintained in all smelling points. A constant pressure difference of 5 cm. of water in the air and odour lines was effected by E monitoring the dial-type manometers.

CHAPTER 7

CHAPTER 7.

PROCEDURES AND RESULTS OF EXPERIMENTS

GENERAL PROCEDURES

Subjects employed the natural sniff in all experiments. Experimental sessions were always of three hours duration and each subject attended the Olfaction Unit twice weekly. Each subject worked at the same time of day each week in order to offset any diurnal variation in olfactory sensitivity that might exist.

The A.C.E.R. Advanced General Ability Test forms AL and AQ, and the 16-Personality Factor Test (Cattell, 1965) were administered to each subject before being employed by the Olfaction Unit.

Three series of stimulus presentations were generated from Rand's "1 Million Random Digits" (Rand Corporation, 1955). Each series incorporated twenty-five presentations of each of twelve smelling stations i.e. three hundred trials which were grouped in blocks of fifty. The only specifications, other than randomness, in designing sequences of presentations were that each block of trials begin with a test station containing odour and that no more than three consecutive presentations of any one station should occur. The first forty-eight presentations served to assist S to attain stability of response and were not used in calculations thus leaving for analysis two hundred and fifty-two trials per three hour sessions. Each series was used in a set order (non-random) to avoid combining results from sessions using the same series which might tend to accentuate sequence effects inherent in a series.

A thirty second presentation cycle was used to allow for

"recovery" of the subject. A rest break of five minutes was given after each block of fifty trials.

The first two sessions of individual experiments that Ss attended was not included in the calculation of results. They were considered to be training sessions during which E was available to assist in any difficulties in procedure that Ss might be experiencing.

EXPERIMENT Is (Sniff-Bottle Technique)

Procedure

Panel X Subjects A, B and C attended eight sessions spread over three weeks during which they undertook 2,400 trials each in order that six thresholds could be calculated per subject. An 8.0×10^{-2}M standard solution of isopropanol was used to prepare the binary series of nine solution concentrations presented to S. This was renewed after every second session.

Subjects were provided with the following type-written instructions:

"There must be an interval of at least one hour between your last meal and the commencement of testing. No perfumes or after-shave lotions and the like to be worn on test days.

It is important that instructions be followed exactly as outlined below so that standardized conditions can be attained.

Detailed Instructions

1. Just before the commencement of testing you will be given a bottle labelled "S" which will contain a sample of the chemical compound to be used as stimulus in the experimental session. Remove the lid of bottle "S" and take one sniff to acquaint yourself with the odour. Replace the lid and hand the bottle to the experimenter.

2. There is a box with a movable lid directly in front of you. The box contains a smelling point T of variable odour concentration. Sometimes the concentration of odorous material in point T will be high and you will be able to detect its presence easily, at other times it will be so low that you may not be able to detect the odour at all. The concentration of odour in point T will vary randomly from trial to trial.

3. Immediately the amber warning light comes on, lift the lid of the box, remove the cap of smelling point T, and on the next inhalation take one good sniff and replace cap. Close the lid of the box.

4. If you detect an odour in smelling point T record your response by pressing button Y; if you are uncertain, press button U. Keep your "uncertain" responses to a minimum i.e. always try to decide whether an odour is present or absent and only use the "uncertain" response as a last resort. Try to maintain a constant timing of events for each trial. There should not be an appreciable time lag from one event to the next in any trial i.e. keep the sequence of events moving.

Remember. * Your response (Y,N,U) is dependent on whether you can detect an odour in smelling point T.

* When lifting the lid of the box do not focus your attention on smelling point T as visual cues could interfere with the odour detection processes.

* Take only ONE sniff of each point at each trial. Give the first natural response that comes to you i.e. do not deliberate for too long as to whether you can detect the odour in point T or not.

* There will be a five minute break at regular

intervals, indicated by a flashing red light, during which subjects may relax but not eat or drink.

* There must be no communication with any other subject while testing is in progress.

* Subjects are asked to report any unusual circumstances, odours etc., to the experimenter by pressing button N repeatedly until the experimenter comes into the test room."

Stimuli were presented at thirty second intervals. E did not give Ss confirmation of their responses in this experiment because it was felt that the frequency of ocurrence of supra-threshold stimuli was great enough for Ss to maintain interest over the three-hour sessions.

Two additional threshold determinations (sessions "7" and "8") were undertaken six months after the initial investigations in order that long term changes in olfactory sensitivity could be ascertained. The procedures followed were similar to those used previously except that a fixed smelling point M, which contained 50 ml. of boiled tap water, was presented to S prior to inhalation of the test stimulus. The subject instructions were ammended so that points 2 and 3 read "

2. There is a fixed smelling point M on your left and a box with a movable lid directly in front of you. The box contains a smelling point T of variable odour concentration whereas the concentration of odour in smelling point M is constant during an experimental session. Sometimes the concentration of odorous material in point T will be high and you will be able to detect its presence easily, at other times it will be so low that you may not be able to detect the odour at all. The concentration of

odour in point T will vary randomly from trial to trial.

3. Immediately the amber warning light comes on, lift the lid of the box, remove the cap of smelling point M, take one good sniff, replace the cap and exhale completely. Whilst exhaling, remove the cap of smelling point T, and on the next inhalation take one good sniff and replace cap. Close the lid of the box."

It was felt that the introduction of the smelling point M would serve as a standard reference point for Ss and that it would serve as an introduction to the identical procedure to be followed in the subsequent experiments. It had not been introduced in the first six sessions because of anticipated contamination from extensive handling by S.

Results

Absolute thresholds were computed using Programmes U379 and U379 sp. (Threshold determination using Probit Analysis) and the University of Tasmania's Elliott 503 Computer (Appendix II).

Thresholds were calculated for those sessions in which the subjects were within the arbitrary restriction of nine false-positive responses or 14% limit.

Results of the first six threshold determinations for each subject are shown in Table 3. Subject B gave up to 54% false-positive responses in the first four sessions and only after E asked him to adopt a stricter criterion did he come below the arbitrary limit. Fig. 8 shows the variation of threshold over the first six sessions together with sessions "7" and "8" except for Subject A who was available for session "7" only. It can be seen that an increase of 0.8 log. units of threshold occured from session 6 to session "7" in the case of Subject A and a decrease of 0.7 log. units in the case of Subject B. The corresponding change in Subject C's threshold was

no greater than the overall variability of his thresholds obtained in sessions 1 to 6.

TABLE 3

Thresholds* obtained by Panel X subjects over six sessions in Experiment I.

Panel X Subjects	Session 1	2	3	4	5	6	Mean Threshold	Standard Deviation
Subject A	0.306	0.381	0.226	0.236	0.204	0.232	0.264	0.061
Subject B	-	-	-	-	2.604	2.745	2.675	0.071
Subject C	1.799	2.235	0.910	2.136	0.239	0.764	1.347	0.750

*Thresholds are expressed as $(M \times 10^{-2})$ of concentration.

Psychometric functions were plotted for each subject. Generally, the degree of departure from the expected ogive shape indicated either that too few concentrations were used at each end of the concentration range or that the thresholds lay towards the end of the range.

A mean ambient temperature of 19.3°C. and a standard deviation 1.9°C. was recorded in the test laboratory over the eight sessions.

Discussion

The question may be raised as to whether the calculation of individual thresholds using Probit analysis is a valid procedure. Probit analysis, as developed by Finney (1952) is not strictly applicable to group threshold determinations involving repeated use of subjects. This misapplication of the method of analysis is even more emphasised when individual thresholds are calculated. However it seemed reasonable to use the programme already established for group threshold work and to make use of the 95% confidence limits contained in it (especially in the adaptation studies where threshold change would be used as a measure of adaptation).

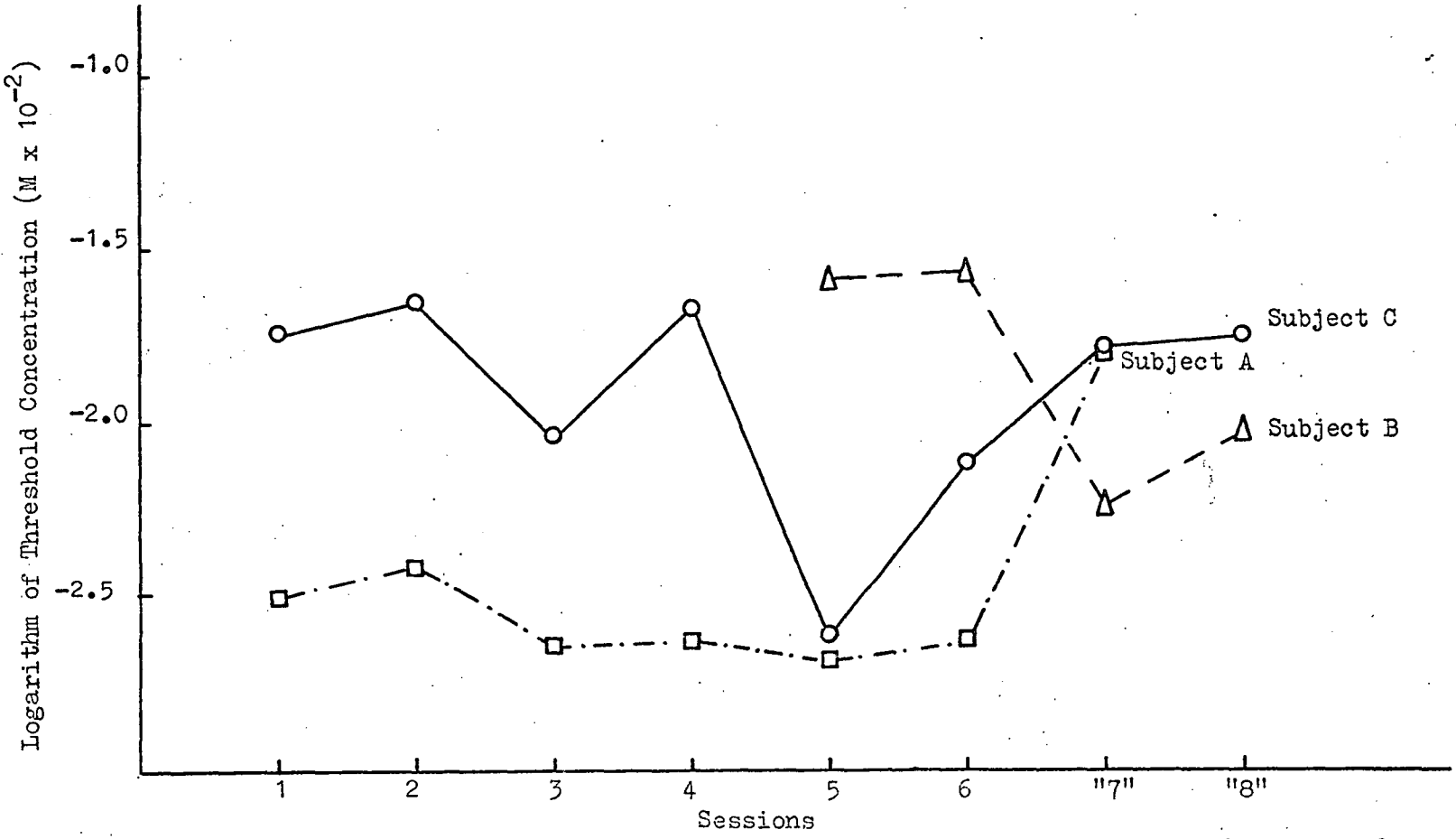


Fig. 8. Panel X Results: Variation of logarithm of olfactory threshold with number of sessions.

There was a marked variation between Ss in threshold change over time. Subject A showed a consistency of response over the first six sessions that was not equalled by Subjects B and C. However the increase in threshold noted in session "7" after a six month interval points to one of the difficulties of long term testing in olfactory sensitivity experiments. A comparison of results of similar experiments separated by a long interval of time may not be a valid procedure. In addition temporary increases in sensitivity may occur as in the case of Subject C during session 5 giving rise to a false estimate of S's overall sensitivity.

One of the problems associated with threshold measure is the use of an arbitrary false-positive rate of response to control for guessing. It was with some reluctance that E advised Subject B to adopt a stricter criterion of positive response after the first four sessions as it was felt that S should be free to use any of the response measures available in an experiment as frequently as they wished without outside interference by E. The rapid stability of Subject B's response in sessions 5 and 6 was linked to a high threshold, as was to be expected, since E had virtually instructed him to be more cautious in his responses. Thus the thresholds obtained in these two sessions were not indicative of Subject B's true capabilities which were probably nearer the threshold obtained in sessions "7" and "8".

EXPERIMENT Id (Air-dilution Technique)

Since this was the first experiment performed using the air-dilution olfactometer it served the purpose of allowing E to detect and remedy any defects in the functioning of the apparatus as well as providing a comparison to the previous experiment where the sniff-bottle technique was used.

Procedure

Subjects D, E and F attended six three-hour sessions (1,800 trials) over a period of three weeks while Subject G was available for the first five sessions only (1,500 trials). A standard 4% of saturation was assigned to the fourth smelling station in the binary series of nine stations shown in Table 1 (p.42). The saturator temperature was set at -17°C. initially, a temperature which had yielded group thresholds of about 4% of saturation in Cheesman's previous experiments where isopropanol was used as the stimulus. In this way it was hoped that the threshold would lie at or near the middle concentration of the series and that the difficulties associated with a threshold placed near the limits of the range (as in Experiment Is) would be overcome.

Pure air was used in the adapting lines of the apparatus and the smelling point M introduced into the system so that Ss would have a standard reference point on which to base their responses to the test point T.

Subject instructions were the same as those used in sessions "7" and "8" of Experiment Is. The inter-trial interval was again set at thirty seconds and the upper limit criterion of false-positive response was the same viz. 14%. No confirmation of response was given to Ss because of the frequent occurence of stimulus of supra-liminal concentration.

Results

Results of the first six sessions are shown in Table 4. A working saturator temperature of -17°C. used in Cheesman's group experiments (Cheesman, 1972) proved unsatisfactory because thresholds deviated from the standard 4% of saturation concentration. This was raised to -12°C. and yielded thresholds close to the standard 40%

saturated concentration, Subject D excepted. The high FPR (0.64) of Subject E at saturator temperature of -17°C. did not allow calculation of thresholds E/4a, E/5b (Appendix V). This ceased when the temperature was raised to -12°C. Thresholds D/6b, D/9b (Appendix V) could not be computed due to a sudden cut-off of positive response adopted by the subject.

D/5a was omitted from results because of suspected contamination of the third smelling point below the standard concentration. A positive response rate of 0.61 was obtained for this point which was the second weakest in the series.

TABLE 4

Thresholds obtained by Panel Y subjects in Experiment I.

Subject D		Subject E		Subject F		Subject G	
Sat. Temp. °C.	Threshold*	Sat. Temp. °C.	Threshold*	Sat. Temp. °C.	Threshold*	Sat. Temp. °C.	Threshold*
-17	+1.46	-17	-1.14	-17	+0.80	-17	+0.41
-17	N.C.	-17	N.C.	-17	+0.33	-17	-0.19
-17	N.C.	-17	N.C.	-17	+0.55	-17	+0.02
-12	+1.44	-12	-0.14	-12	+0.08	-12	+0.17
-12	+0.86	-12	0.41	-12	+0.15	-12	+0.41
-12	N.C.	-12	0.15	-12	-0.01	-	-

*Threshold expressed in twofold steps from standard concentration (4% of saturation = 0.149 mm. Hg)

N.C. Threshold not calculable.

A mean temperature of 18.5°C. and a standard deviation of 1.0°C. was recorded in the test laboratory.

Discussion

It can be seen from Table 4 that the working saturator temperature of -12°C. was generally superior to the -17°C. used by

Cheesman in that thresholds were closer to 4% of saturation. This may be due to individual differences in the subjects employed, Panel Y Subjects being less sensitive to isopropanol than Cheesman's subjects.

Subject D's results are anomalous in this respect although the sudden cut-off in positive response at about the threshold point suggests that personal characteristics of responding to stimuli could be operating. This phenomenon, coupled with a relatively high threshold suggests that the subject was only reporting "obvious" smelling points and ignoring others of which she was doubtful i.e. she adopted a high criterion for positive response.

Subject G's results indicate that -17°C. or -12°C. saturator temperature were equally as effective in obtaining a threshold close to 4% saturation concentration. The overall results supported the use of -12°C. as a satisfactory saturator temperature for Panel Y Subjects. Consequently this temperature was maintained for the remainder of the experiments employing the air-dilution technique.

There did not appear to be any contamination of the adapting odour line during the experiment so it was decided to use the smelling point M in a similar way in Experiment II.

EXPERIMENT IIs (Sniff-bottle technique)

This experiment was the first in which signal detection techniques were used to measure subject sensitivity. The traditional method in which one stimulus concentration only is presented in a single session was adhered to. Because of the large number of trials required in the Yes-No method it was decided to adopt the rating procedure which is more economical of time. In this way it was possible to obtain a value of the detectability index after every two similar testing sessions or 504 trials (252 signal present, 252 signal absent)

This meant that S's responses in two similar sessions had to be combined. Unfortunately Subjects B and C could not attend all sessions so that the index of detectability could not be calculated at all concentrations for these subjects.

Procedure

Subjects (A, B and C) were tested at five concentrations within the range of threshold concentrations obtained by Subjects A and C viz. 0.366×10^{-2}M, 0.392×10^{-2}M, 0.980×10^{-2}M, 1.141×10^{-2}M and 1.475×10^{-2}M. As mentioned previously, the mean threshold concentration of 2.675×10^{-2}M obtained by Subject B was suspect. Hence the range of concentrations employed was not extended to include this value.

The variation of sensitivity with stimulus concentration was thus investigated over a 0.6 unit logarithmic range of concentration beginning at about threshold for Subjects A and C and 1 logarithm unit "below threshold" in the case of Subject B. Each subject attended two sessions at each of the five concentrations wherever his/her timetable made this possible. Thus Subject A attended ten three hour sessions (3,000 trials), Subject B attended eight sessions (2,400 trials) and Subject C attended nine sessions (2,700 trials). The experiment extended over a period of eight weeks.

Subjects were provided with a type-written copy of the following instructions -

"The next series of experiments will differ from Stage I experiments in two ways. Firstly, the probability of smelling point T containing an odour will be 50% i.e. there will be as many presentations containing odour as not containing odour. The order of presentation will be random i.e. smelling point T will be equally as likely to contain an odour as to not contain an odour. Furthermore the

probability of its containing an odour (50%) will be completely independent of the preceding or following presentations. The subject should guard against the "gambler's fallacy" i.e. a "long" sequence of presentations not containing odour does not necessarily mean that the next presentation will contain an odour. The probability of its containing an odour is still 50%.

Secondly, the response will involve the use of 6 buttons.

Press --

Button 1 if you are very certain that odour is present.

Button 2 if you are quite certain that odour is present.

Button 3 if you are uncertain, but think that odour is probably present.

Button 4 if you are uncertain, but think that odour is probably not present.

Button 5 if you are quite certain that odour is not present.

Button 6 if you are very certain that odour is not present.

Subjects are free to use all categories of response at any time.

After you have recorded your response either a green light or a red light will come on. A green light means that smelling point T contained an odour, a red light means that it did not.

NOTE:

1. The test odour to be used in each block of trials will be presented before the commencement of each new block of trials.
2. Other than for the variations mentioned, the routine is similar to Experiment I."

It will be noted that Ss were given information about the probability of signal occurence and were provided with information concerning the appropriateness of their response after very trial. The latter was considered important because of the low concentrations employed and the necessity of ensuring that S was aware of the nature of the stimulus and that boredom was offset. The inter-trial interval was kept at thirty seconds.

Results

Initially the sensitivity index d' was to be used as a sensitivity measure but plots of hit rate P(S/s) against false alarm rate P(S/n) using normal deviate axes were often non-linear and of slope other than unity. Also the number of points plotted was reduced because subjects seemed to be unwilling to use all response categories. Hence the index d_e', which can be used in the unequal variance case was adopted exclusively. (If P(S/s) is plotted against P(S/n) on double probability paper then d_e' is defined as twice the value of either Z(S/s) or Z(S/n), ignoring signs, at the point where the ROC curve intersects the negative diagonal). The non-parametric measure 2 arc sin $\sqrt{P(A)}$ was considered inappropriate for the degree of mathematical precision required in deriving relationships despite the advantages of the smaller numbers of trials needed to calculate this statistic. Gradients of ROC curves were obtained using a Least Squares programme (Appendix II) which was used in conjunction with the PDP/8e computer since maximum likelihood programmes were not available. Results of combined sessions are shown in Table 5.

TABLE 5.

Values of d_e' obtained by Panel X subjects in combined sessions in Experiment II.

Panel X Subjects	Test Concn. ($M \times 10^{-2}$) 0.366	0.392	0.980	1.141	1.475
Subject A	3.545	2.709	2.738	2.756	3.073
Subject B	2.065	-	2.685	-	2.601
Subject C	3.495	3.103	3.470	2.882	-

Results of subjects who attended one session only at a particular concentration are not included.

Rate of change of log. d_e' with log. test concentration was as follows: Subject A -0.059, Subject B 0.184, Subject C -0.056. No significant trends in false positive rate (FPR) were noted except that Subject B reverted to rates which were generally above the criterion of 14% of Experiment I.

Discussion

It can be seen that the range of test concentrations used was not great enough to yield a significant systematic change in sensitivity except in the case of Subject B. Ideally it would have been of interest to extend the concentration range to at least forty times the mean subject threshold as originally proposed, but this was not possible in view of the limited time available for Ss to attend sessions. Moreover E wished to commence Section III experiments before S's contract with the Olfaction Unit ceased. The experiment served as an introduction to the use of rating scales but was without results of any significance.

EXPERIMENT IId (Air-dilution technique)

In this experiment use of the signal detectability measurement

of sensitivity was investigated using the air-dilution method of stimulus presentation. The experiment was conducted in two stages.

Stage I

Procedure

During first stage five three hour sessions (1,500 trials) were conducted over three weeks in which Panel Y Subjects (D, E, F and G) were presented with one stimulus concentration only per session. Concentrations used were 0.149, 0.299, 0.597, 1.194 and 2.389 mm. Hg. ranging from 40% saturation to 1.6 log. units above this standard concentration. Each session consisted of 126 trials on which a signal was present and 126 trials in which a signal was absent. Subject instructions were the same as those used in Experiment IIs and the inter-trial interval was again set at thirty seconds.

Results

Table 6 and Figs. 9, 10 and 11 depict results of the Stage I experiment. Although five concentrations were used, none of the plots of log. d_e' against log. concentration consist of five points since subjects used only two categories of response e.g. 1 and 6 or 3 and 4 when stimulus concentrations appeared to be very high or very low. This occured despite the fact that they were encouraged to make use of all categories. Table 7 shows the gradients of plots of log. d_e' against log. test concentration.

TABLE 6

Values of d_e' obtained by Panel Y subjects in Experiment IId where one stimulus concentration only was presented per session

Panel Y Subjects	Test Concentration (mm. Hg). 0.149	0.299	0.597	1.194	2.389
Subject D	1.629	2.132	N.C.	2.954	N.C.
Subject E	1.374	2.632	3.126	N.C.	N.C.
Subject F	2.449	3.937	3.060	N.C.	N.C.
Subject G	3.835	4.145	N.C.	N.C.	N.C.

N.C. d_e' not calculable due to insufficient response categories

TABLE 7

Experiment IId log. d_e' against log. test concn. (mm. Hg). Stage I

	Gradient of graph
Subject D	0.28
Subject E	0.59
Subject F	0.16
Subject G	N.C.

N.C. Not calculable 2 points only.

Subject E displayed a decreasing false positive rate (FPR) with increasing stimulus intensity as might be expected, while Subject D maintained consistently high FPR in all Signal Detectability experiments. This contrasted with her low FPR in Experiment I.
A mean ambient temperature of 18.5 ^{o}C. and a standard deviation of 1.0^{o}C. was recorded over Stage I and Stage 2 experiments.

Discussion

Although the number of trials used to calculate d_e' was half the minimum number necessary to obtain reliability it was felt that this number should be allowed to provide a fair comparison with

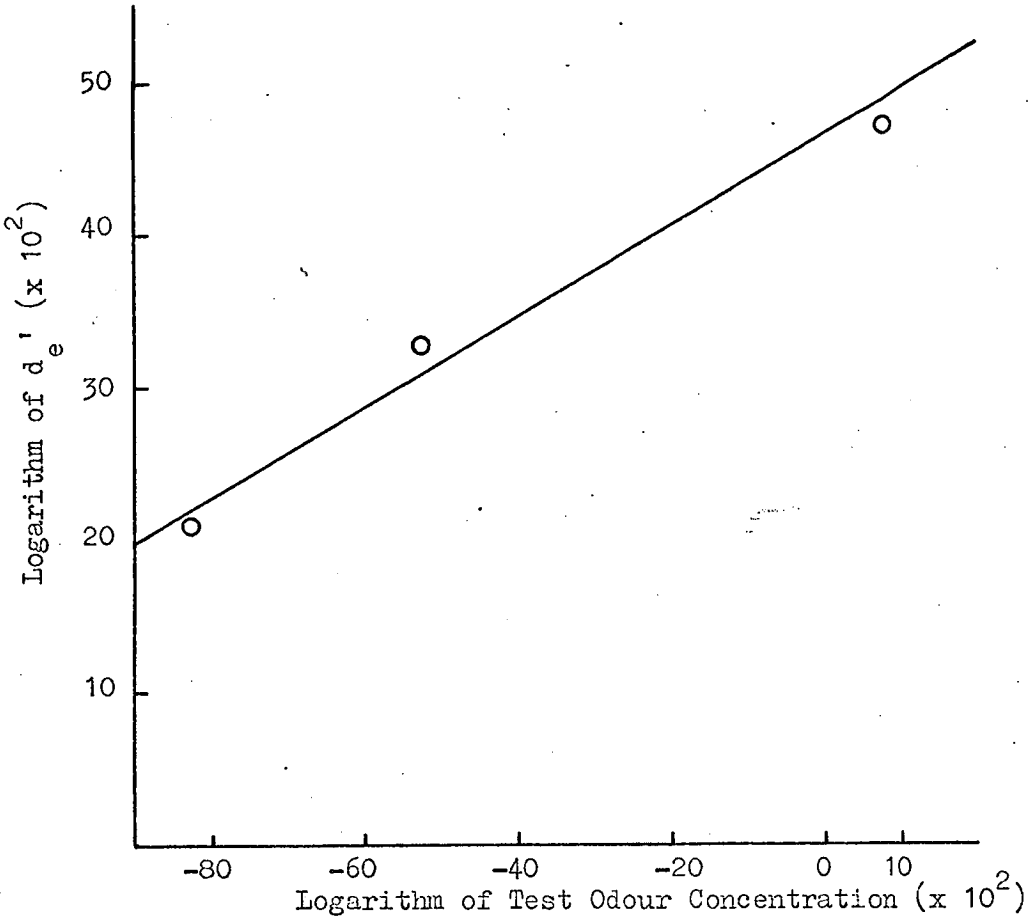


Fig. 9. Variation of log. d_e' with log. test odour concentration for Subject D. Each point was obtained in a single session of 126S : 126N trials.

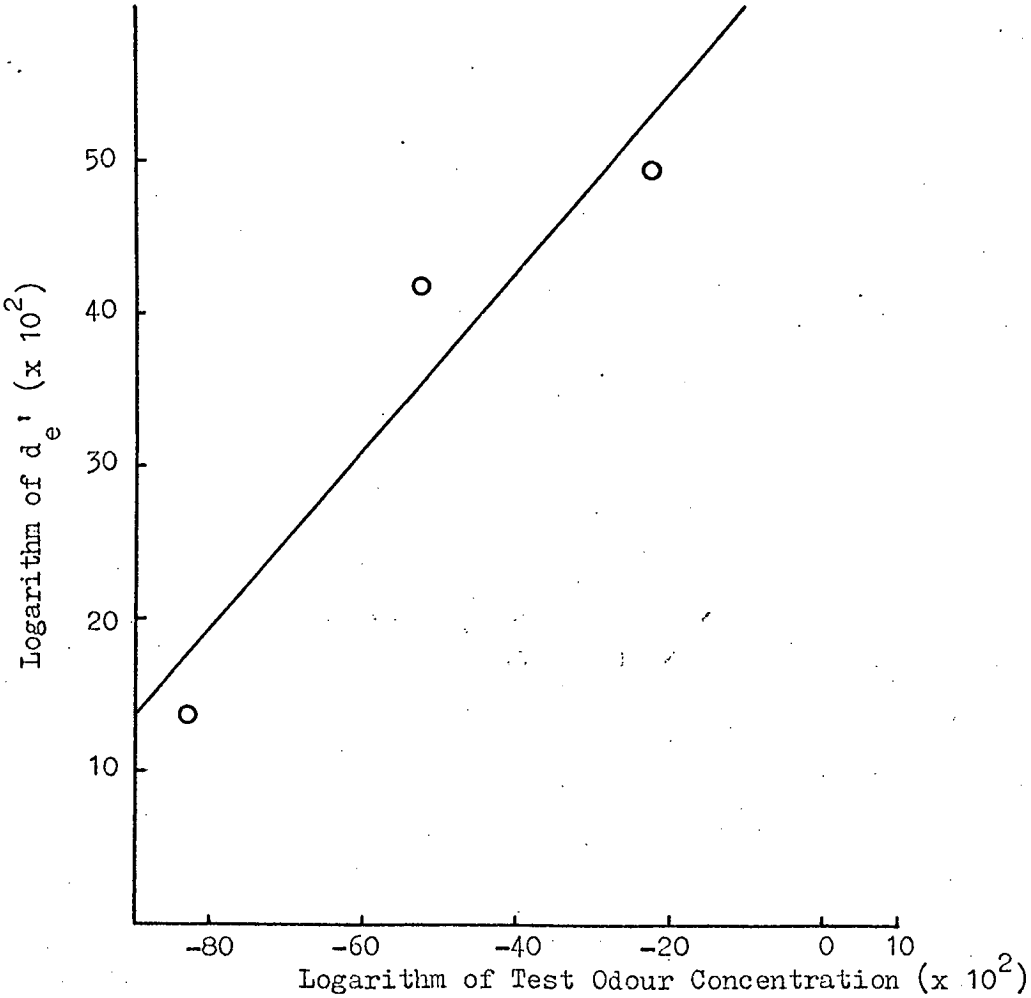


Fig. 10. Variation of log. d_e' with log. test odour concentration

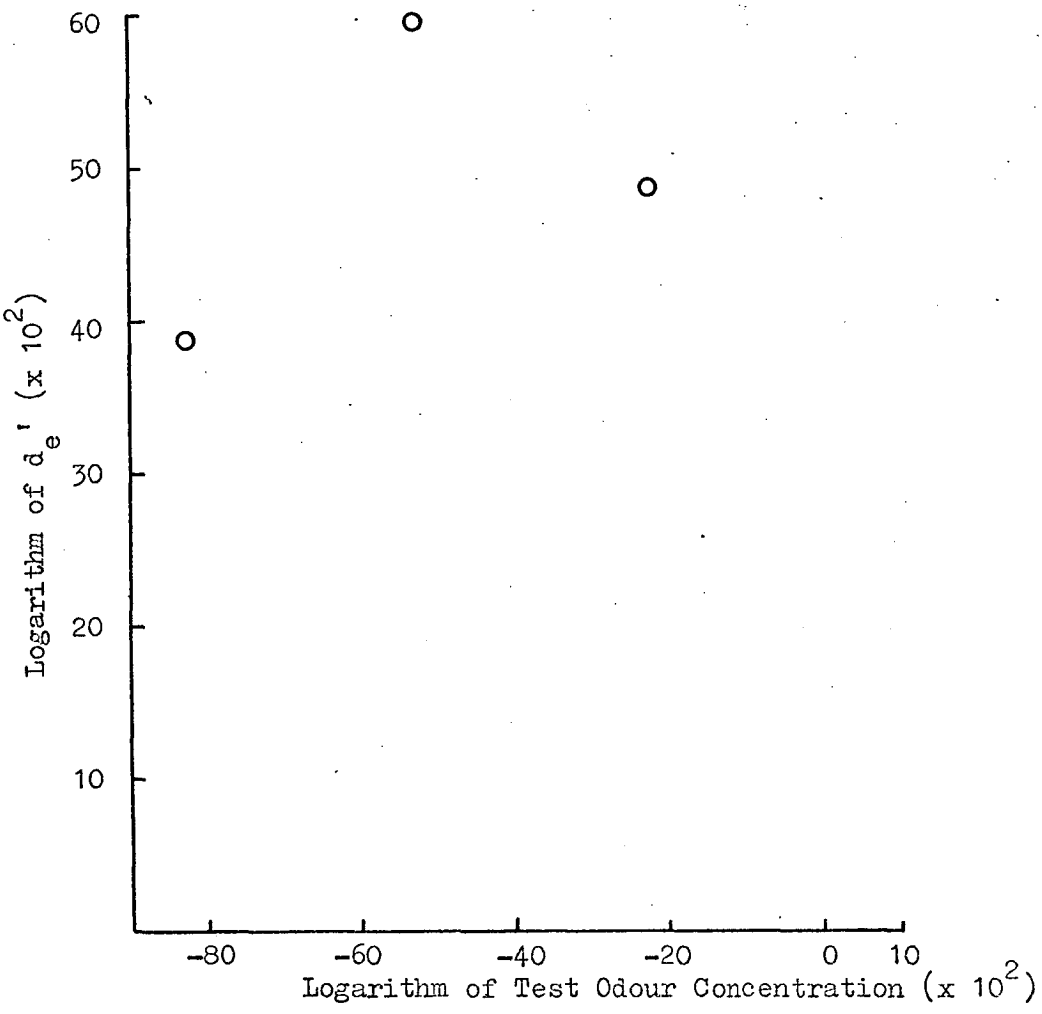


Fig. 11. Variation of log. d_e' with log. test odour concentration for Subject F. Each point was obtained in a single session of 126S : 126N trials.

Stage 2 technique of stimulus presentation. The high incidence of the two-category response resulted in d_e' being calculable on three occasions in the case of Subjects D, E and F and on only two occasions in the case of Subject G. Thus the reliability of a rectilinear relationship between log. test odour concentration and log. sensitivity is low. It appears that subjects tend to adopt an "easy" two-response categorization when only one stimulus concentration is presented per session. This could be due to boredom resulting from lack of variety of stimulation.

Stage 2

Procedure

In view of the difficulties associated with subject responses that were encountered in Stage 1 a binary series of six concentrations ranging from about 0.25 threshold to eight times threshold was used in a single session. It was anticipated that this would result in Ss being more willing to use all six response categories and thus enable d_e' to be calculated on more occasions.

Panel Y Subjects attended 5 three-hour sessions (1,500 trials) over a period of three weeks. Test concentrations of 0.037, 0.075, 0.149, 0.299, 0.597, 1.194 mm. Hg concentration were presented 21 times each during a session. The remaining 126 trials consisted of "blanks" only. Results from the five sessions were combined so that the total number of presentations of each concentration (105) was of the same order as that used in Stage 1. (126).

Subject instructions were those used in Stage 1 and the inter-trial interval was set at thirty seconds.

Results

The values of d_e' calculated over the five testing sessions are shown in Table 8.

TABLE 8

Values of d_e' obtained by Panel Y subjects in Experiment IId where six stimulus concentrations were presented per session

	Test Concentration (mm. Hg)					
Panel Y Subjects	0.037	0.075	0.149	0.299	0.597	1.194
Subject D	0.418	0.670	1.070	2.347	2.815	N.C.
Subject E	0.315	0.672	0.801	1.782	2.895	N.C.
Subject F	1.505	3.013	3.549	4.335	N.C.	N.C.
Subject G	0.580	1.580	1.536	2.625	N.C.	N.C.

N.C. d_e' not calculable due to insufficient response categories

Generally d_e' values obtained by Ss are lower than those calculated for corresponding concentrations presented in Stage 1. Also the incidence of non-calculable results is smaller. This is reflected in Figs. 12, 13, 14 and 15 which show the variation of log. d_e' with log. test odour concentration where it can be seen that five points could be plotted in the case of Subjects D and E and four points in the case of Subjects F and G. Gradients of plots are shown in Table 9.

TABLE 9

Experiment IId. log. d_e' against log. test concn. (mm. Hg)

Stage 2

	Gradient of graph
Subject D	0.73
Subject D	0.78
Subject F	0.45
Subject G	0.65

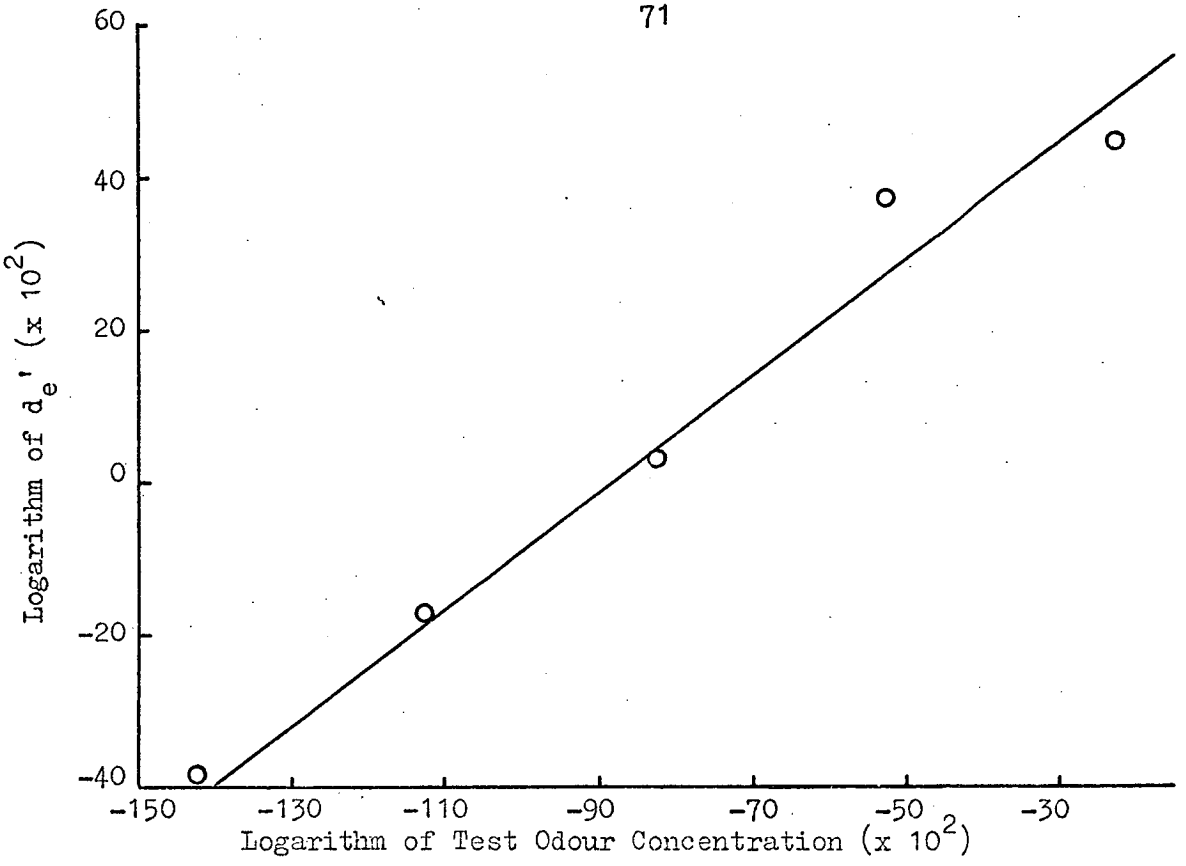


Fig.12. Variation of log. d_e' with log. test odour concentration for Subject D. Each point was obtained from a combination of 5 testing sessions in which six test odour concentrations were presented.

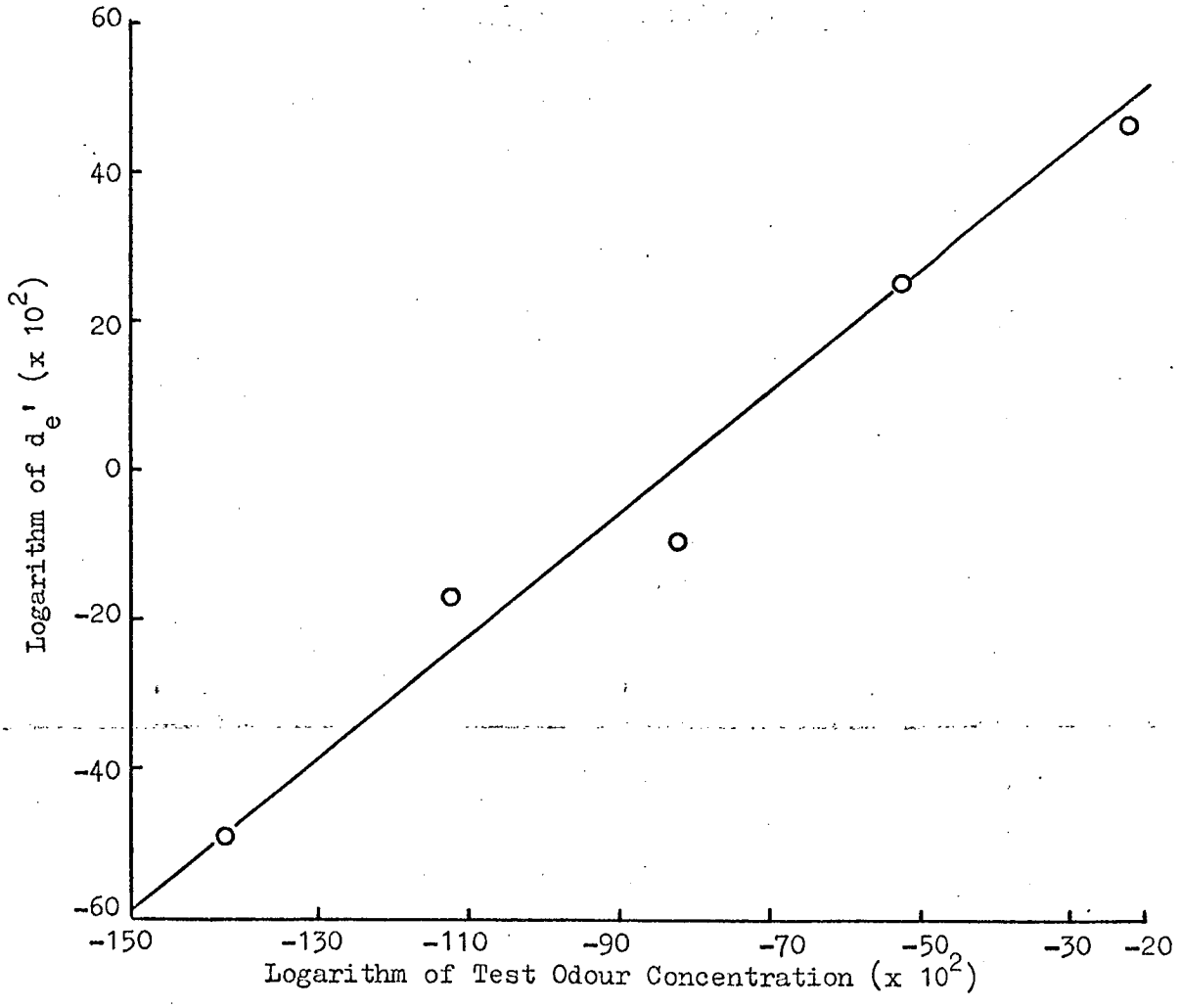


Fig. 13. Variation of log. d_e' with log. test odour concentration for Subject E.

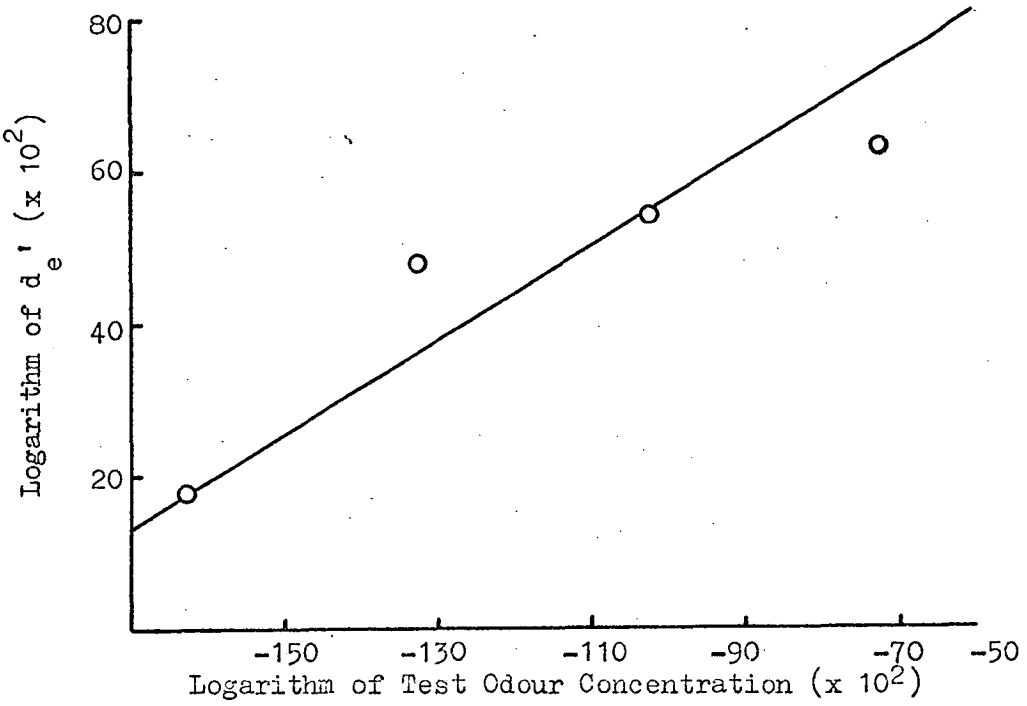


Fig. 14 . Variation of log. d_e' with log. test odour concentration for Subject F. Each point was obtained from a combination of 5 testing sessions in which six test odour concentrations were presented.

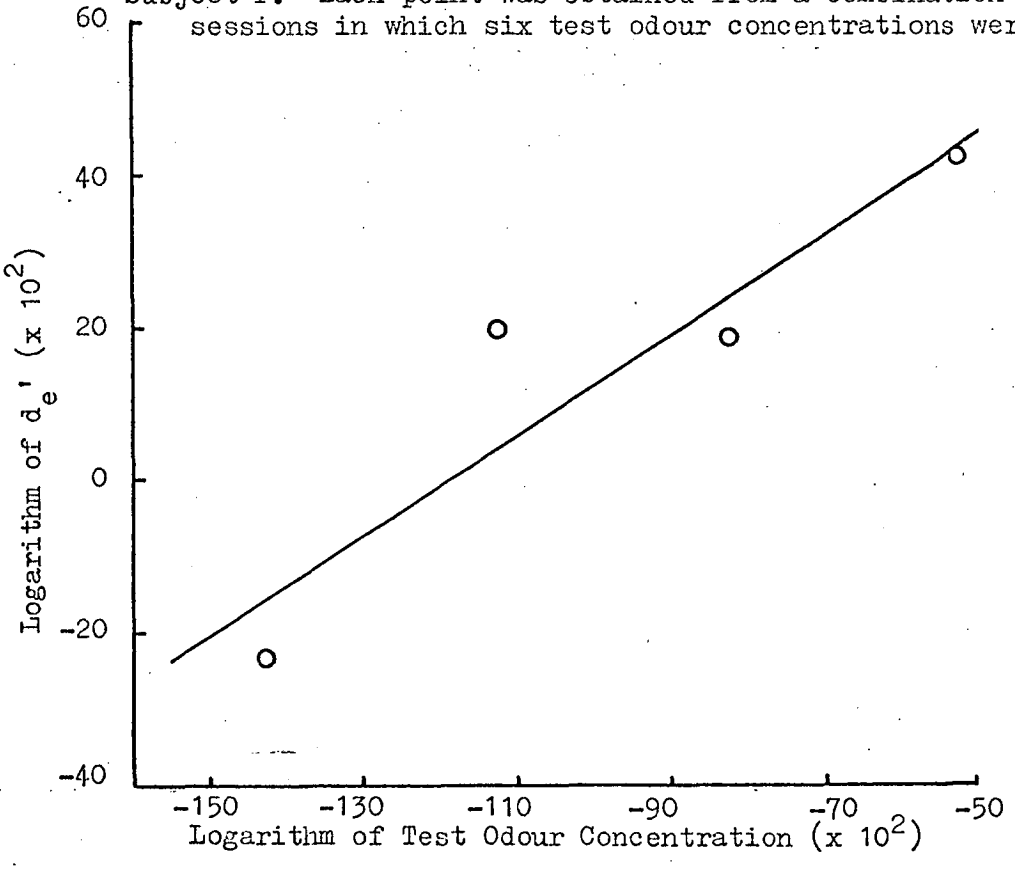


Fig. 15 . Variation of log. d_e' with log. test odour concentration for Subject G. Each point was obtained from a combination of 5 testing sessions in which six test odour concentrations were presented.

Discussion

It is obvious that the utilization of multiple stimulus concentrations within a single test session yields more useful and consistent data than the single concentration per session. The apparent decrease in sensitivity as evidenced by the lower values of d_e' for equivalent stimulus strengths may be related to the fact that Ss were not told how many concentrations were being employed. The gradients of the log. stimulus concentration vs. log. sensitivity graphs are more consistent both within and between Ss in the Stage 2 experiment which seems to indicate that assigning a common false alarm rate to multiple stimuli presented within the one testing session may be a valid procedure.

EXPERIMENT IIIa (Sniff-bottle technique)

Experiment IIIa was the first of three experiments designed to investigate the effects of co-adaptation on subject sensitivity. The change of test stimulus threshold with adapting stimulus concentration was to be used as an index of co-adaptation in this experiment.

Procedure

The physical arrangements were similar to those of sessions "7" and "8" of Experiment Is. Bottle M contained the adapting odour in place of boiled water. Solutions of isopropanol were prepared accurately at concentrations at or about 8×10^{-2}M, 6×10^{-2}M, 4×10^{-2}M, 2×10^{-2}M, 1×10^{-2}M and 0.5×10^{-2}M and were used as adapting stimuli. (It was impossible to prepare duplicate solutions of exactly the same concentration using the pipette technique). Only one concentration was used per testing session. Solutions were presented in ascending order of concentration over sessions. Subjects

did not undergo the same number of sessions for all adapting odour concentrations because of restrictions arising from the frequency of solution renewal.

Subjects A and B attended 14 three-hour sessions (4,200 trials) and Subject C attended 15 sessions (4,500 trials) over a period of eight weeks. Instructions to subjects were identical with those given in sessions "7" and "8" of Experiment Is (p.53). S was not given information concerning the appropriateness of his responses because the employment of nine test stimulus concentrations was considered to be sufficient to offset boredom equally as well as provision of this type of information.

The exposure duration of the adapting stimuli and the interval between presentation of the adaptive and test stimulus was not controlled by E. It was felt that since Ss were employing the natural sniff they would be more likely to adopt a procedure which would optimize sensitivity than if duration were strictly controlled. In any case the experiments were to provide a comparison with previous experiments of Cheesman where durations of exposure were uncontrolled. The inter-trial interval was set at thirty seconds.

Preliminary work revealed that a second dilution series ($\lambda_1 = 16.0 \times 10^{-2}$M) was required to ensure that the threshold fell somewhere near the mid-point of the range of concentration. This was necessary since thresholds near either end of the range may be suspect (Mayne, 1953).

A mean laboratory temperature of 19.3°C. (standard deviation 1.9°C.) was recorded.

Results

The thresholds obtained for various adapting odour concentrations

are shown in Table 10.

TABLE 10

Threshold values for a given adapting odour concentration: Panel X subjects.

Subject A		Subject B		Subject C	
Adapting Odour Concn. ($M \times 10^{-2}$)	Threshold Concn. $M \times 10^{-2}$)	Adapting Odour Concn. ($M \times 10^{-2}$)	Threshold Concn. ($M \times 10^{-2}$)	Adapting Odour Concn. ($M \times 10^{-2}$)	Threshold Concn. ($M \times 10^{-2}$)
0.514	1.872	0.249	1.593	0.249	1.471
0.580	0.627	0.514	0.544	0.580	1.057
1.018	0.893	0.580	0.382	0.580	1.500
1.018	1.098	1.018	1.083	0.994	0.943
1.950	1.014	1.950	2.773	0.994	1.329
1.950	1.640	4.013	0.830	1.950	0.934
4.013	1.491	4.013	1.166	1.950	1.516
6.219	1.554	6.219	0.911	4.013	1.406
6.219	0.815	7.565	1.312	4.013	2.802
7.565	1.114	7.805	1.648	6.219	1.311
7.565	0.834	7.840	1.570	7.805	0.971
7.910	N.C.	7.910	6.675	7.805	1.511
8.375	0.771	7.910	6.105	7.840	0.716
8.375	0.925	8.375	2.866	7.840	0.847
				7.910	4.755

N.C. Not calculable

The relatively large number of sessions and the 1.21 log. unit range of adapting odour concentrations used, although designed to give an adequate test of Cheesman's hypothesis, gave rise to greater overall variability of response (Table 10) than was evidenced by Mayne's subjects who worked in the 0-15 times threshold range.

Where two sessions with identical adapting odour concentrations occured, the results were combined to give a "combination threshold" (Appendix III, Tables J, K and L). This was shown to be a valid procedure for Subject C and of dubious consequence for

Subject A (Table 11).

TABLE 11

Experiment III (a): Panel X subjects.
Difference between single and combined sessions.

Subject	Test	Significance Level
A	Related samples t-test	$0.05 < p < 0.10$
C	Wilcoxon Signed-Ranks test	$p < 0.20$ not significant

Validity could not be checked statistically in the case of Subject B because of the small number of sessions that could be combined. The results of combined sessions with the corresponding single sessions serving as "limits" are shown in Fig. 16, 17, 18 where threshold is plotted against adapting concentration logarithmically. Gradients of graphs and range of adapting odour concentrations used in the calculation of gradients are given in Table 12.

TABLE 12

Plot of log. threshold against log. adapting odour concentration.

Subject	Range of adapting odour concn.	Gradient
A	T - 15T	0.71
B	*? T - 0.48T	1.54
C	T - 10T	0.30

* It will be recalled that some doubt was cast on the validity of Subject B's threshold obtained in Experiment Id.

Discussion

It is evident that the results lack the consistency necessary to justify their use as a measure of co-adaptation in the way that Cheesman has described. The experimental variance

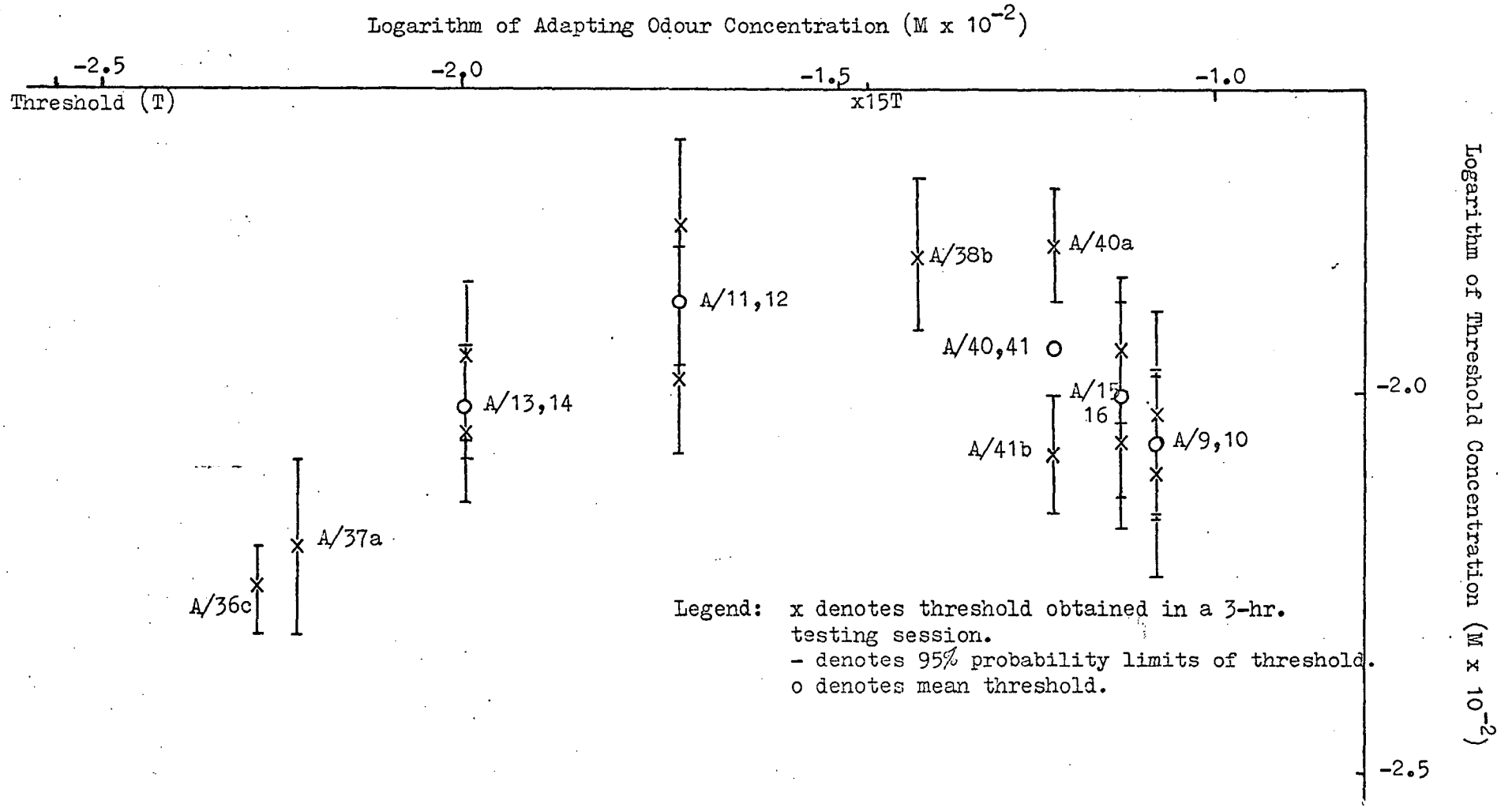
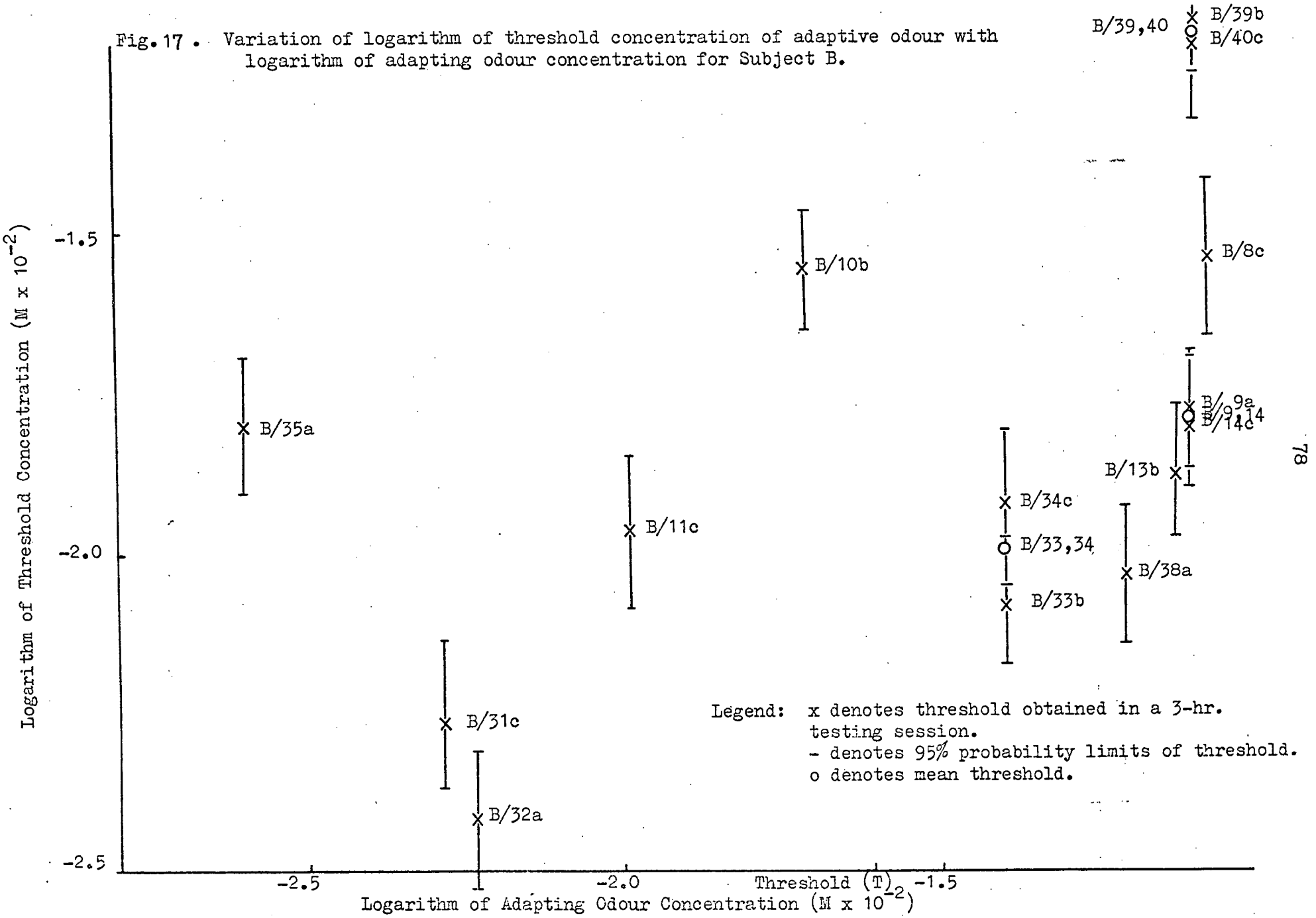


Fig.16. Variation of logarithm of threshold concentration of adaptive odour with logarithm of adapting odour concentration for Subject A.

Fig. 17 . Variation of logarithm of threshold concentration of adaptive odour with logarithm of adapting odour concentration for Subject B.



Legend: x denotes threshold obtained in a 3-hr. testing session.
- denotes 95% probability limits of threshold.
o denotes mean threshold.

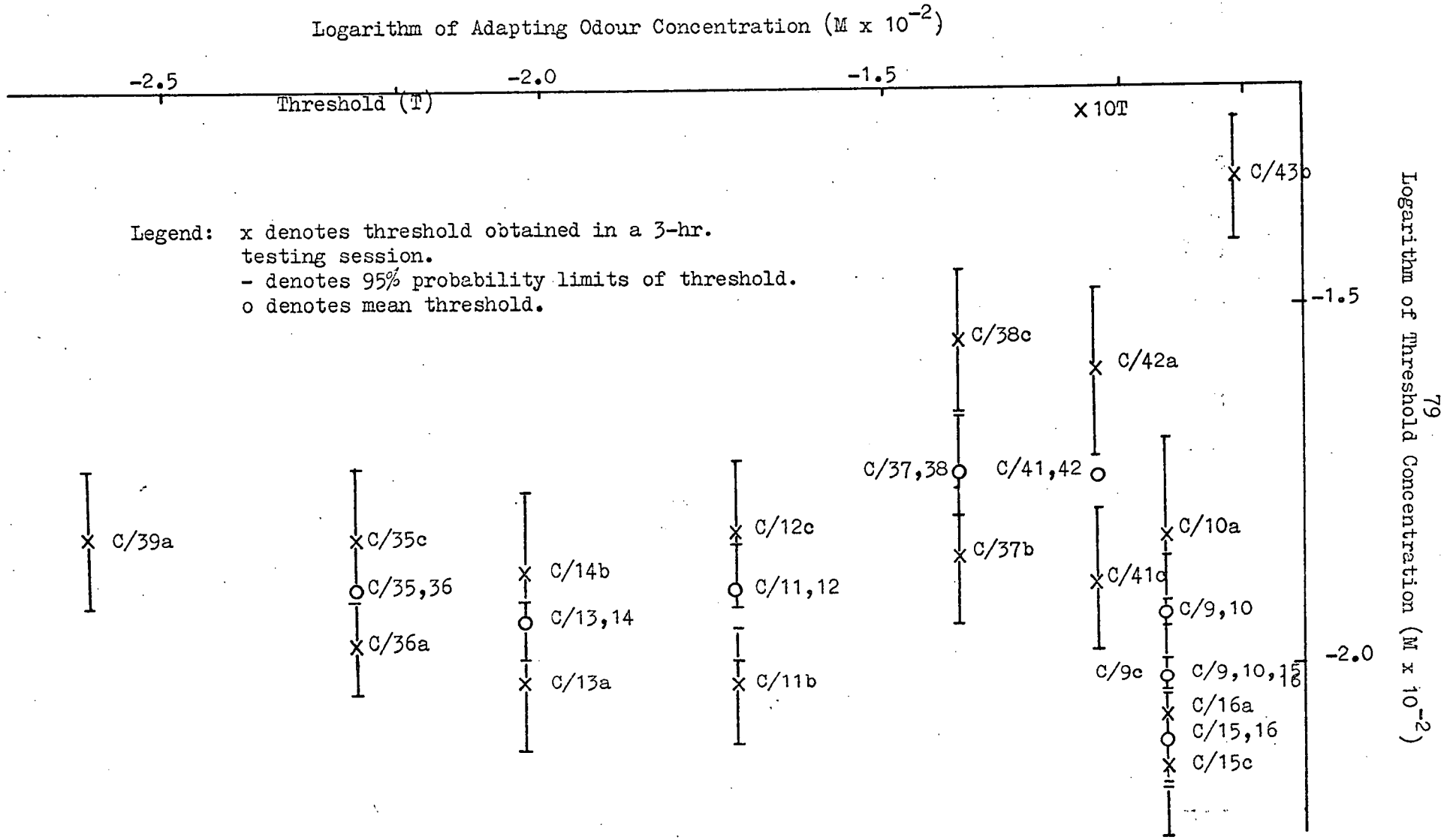


Fig. 18. Variation of logarithm of threshold concentration of adaptive odour with logarithm of adapting odour concentration for Subject C.

is considerably greater than one would expect with this range of adapting odour concentration which, although extending beyond the ten times threshold limit advocated by Cheesman and Mayne, is fairly moderate. The anomalous thresholds associated with the adapting odour concentration of 7.910×10^{-2}M casts doubt on the purity of the solutions used since a check of preparation procedures and threshold calculations does not reveal any errors. It is possible that Ss may have tended to report on the presence or absence of odour in the adapting smelling point although this is unlikely since the 7.910×10^{-2}M adapting solution was used near the end of the experiment. The gradients shown in Table 12 have been calculated within narrow ranges of adapting odour concentration. They cannot be considered to represent a rectilinear relationship between log. adapting odour concentration and log. threshold concentration because of the wide scatter of points involved. It seemed that the Cheesman measure of co-adaptation was not suited to experiments in which individual subject thresholds were obtained. Alternatively the use of aqueous solutions of odorous compounds in adaptation studies may have led to variable contamination effects which were beyond E's control. It had been planned to repeat Experiment IIIa using the air-dilution technique and thus to investigate the effects of stimulus presentation techniques on the co-adaptation measure. Unfortunately Ss were no longer available for testing so the experiment was cancelled.

EXPERIMENT IIIb (Sniff-bottle technique)

Experiment IIIb was the first of two investigations to be undertaken in to the use of signal detectability measures in co-adaptation experiments. Because of the constraint of subject availability it was only possible to conduct a limited number of

testing sessions.

Procedure

Subject A attended four testing sessions (1,200 trials) while Subjects B and C attended three sessions (900 trials). The sessions were spread over a two week period. Three adapting odour concentrations of 0.424×10^{-2}M, 0.877×10^{-2}M and 1.441×10^{-2}M which were based on one, two and four times Subject A's mean threshold concentration were employed. Subjects A and C were tested at 0.424×10^{-2}M and 1.441×10^{-2}M concentrations only because of the limited time available and the arrangements which were made for stimulus preparation. Test odour concentrations of 0.326×10^{-2}M and 1.186×10^{-2}M were chosen, again on the basis of Subject A's mean threshold.

Subjects did not undergo the same number of trials under the same conditions since it was found that it was necessary to incorporate two test stimuli in some sessions so that subjects could be tested at most concentrations before the programme finished. Details of testing sessions may be found in Appendix III.

Subjects received the same type-written instructions that were used in Experiment II. E informed S of the appropriateness or otherwise of his response after every trial. S employed the natural sniff and the inter-trial interval was set at thirty seconds. The interval between presentation of the adaption and test stimuli and the exposure duration of the adapting stimuli were uncontrolled for reasons mentioned in Experiment IIIa.

Results

Values of d_e' obtained under the various test conditions are

shown in Table 13.

TABLE 13

Values of d_e' obtained by Panel X subjects for a given test and adapting odour concentration.

Test Concn. ($M \times 10^{-2}$)	Subject A Adapting Odour Concn. ($M \times 10^{-2}$)			Subject B Adapting Odour Concn. ($M \times 10^{-2}$)			Subject C Adapting Odour Concn. ($M \times 10^{-2}$)		
	1.441	0.877	0.424	1.441	0.877	0.424	1.441	0.877	0.424
0.326	0.913 (252)	-	1.472 (126)	0.970 (252)	0.810 (126)	0.979 (126)	3.444 (252)	-	3.683 (252)
0.326	1.101 (126)	-	-	-	-	-	-	-	-
1.186	2.692 (126)	-	2.205 (126)	-	1.930 (126)	1.651 (126)	4.349 (252)	-	-

The number of trials used to determine a given d_e' value are shown under the d_e' value

Subject A has again displayed consistency in that the values of d_e' for test odour concentration 0.326×10^{-2}M with adapting odour concentration 1.441×10^{-2}M are similar when 252 trials and 126 trials are used. Variation of d_e' with adapting odour concentration is in the expected direction for the test concentration 0.326×10^{-2}M in contrast to the 1.186×10^{-2}M test concentration. Subject B maintained a high FPR, while Subjects A and C were consistently low in this respect.

A mean temperature of 19.0°C. and a standard deviation of 1.9°C. was recorded.

Discussion

The small number of trials in this experiment makes it difficult to draw conclusions from the results. However the change of direction of the d_e' - adapting odour concentration relationship

with test odour concentration suggests that perhaps test odour concentration is an important factor in adaptation measurement.

Subject characteristics such as consistency of response in the case of Subject A and high FPR in the case of Subject B do not alter when adapting stimuli are introduced into the test situation. Thus the analysis of results using similar methods to the non-adapting test situation seems justified.

EXPERIMENT IIIb (Air-dilution technique)

In view of the greater consistency of results obtained in Stage 2 of Experiment II as compared to Stage 1 of the same experiment it was decided to adopt the Stage 2 procedure of multiple test stimulus presentation within the one experimental session.

Procedure

Panel Y Subjects (D, E, F and G) attended ten testing sessions (3,000 trials) each over a period of five weeks. Six test odour concentrations ranging from 0.25 times the standard 40% saturated concentration in two-fold steps of up to eight times the standard concentration, were presented twenty-five times each in all testing sessions. The probability of signal occurence was again set at 0.50. The five adapting stimuli covered a 0.9 log. unit range. The actual concentrations used were 0.171 mm. Hg, 0.237 mm. Hg, 0.417 mm. Hg, 0.692 mm. Hg and 1.018 mm. Hg. Only one adapting odour concentration was used per session so that each concentration was used in two sessions and the results of duplicate sessions were combined. Thus subject sensitivity to a test concentration under a given adapting concentration was calculated on forty-two test stimulus presentation.

Adapting stimuli were presented in ascending order of

concentration over sessions to avoid adsorption effects in the glass flow lines.

Subject instructions were identical to those given in Experiment II. The inter-trial interval was thirty seconds. Intervals between presentation of adaptation and test stimuli and exposure durations of adaptation stimuli were uncontrolled. E informed S as to whether a signal was present or absent on any trial.

Results

Values of d_e' for each test odour concentration at the various adapting odour concentrations for each subject are shown in Table 14 (A detailed, tabular summary of Panel Y's results appear in Appendix IV). It was not possible to calculate d_e' where subjects had used too few categories of response such as when perceived intensity of the test stimulus was very high e.g. a strong test stimulus used in conjunction with a weak adapting stimulus. Log. d_e' was plotted against log. test concentration for each adapting concentration and gradients computed (Table 15). Similarly log. d_e' was plotted against log. adapting concentration for each test stimulus concentration (Table 16).

NOTE: Results of Stage 2 of Experiment IId (zero adapting odour concentration) have been included in Tables 14, 15 and 16 for completeness. A mean temperature of 18.5°C. and a standard deviation of 1.0°C. was recorded.

TABLE 14

Experiment III (b) Results: Panel Y subjects.

Test. Concn. (mm. Hg)	Adapt. Odour (mm. Hg)	d_e' Subject D	Subject E	Subject F	Subject G
1.194	0	N.C.	N.C.	N.C.	N.C.
1.194	0.171	N.C.	3.290	N.C.	N.C.
1.194	0.237	N.C.	N.C.	N.C.	N.C.
1.194	0.417	N.C.	N.C.	N.C.	N.C.
1.194	0.692	N.C.	N.C.	N.C.	N.C.
1.194	1.018	N.C.	2.876	N.C.	N.C.
0.597	0	2.815	2.895	N.C.	N.C.
0.597	0.171	N.C.	1.803	N.C.	3.230
0.597	0.237	N.C.	2.334	N.C.	2.526
0.597	0.417	2.230	1.465	3.153	N.C.
0.597	0.692	0.460	0.974	N.C.	0.935
0.597	1.018	0.913	0.442	3.224	N.C.
0.299	0	2.347	1.782	N.C.	2.625
0.299	0.171	1.869	1.489	N.C.	2.012
0.299	0.237	0.510	1.792	3.022	1.269
0.299	0.417	0.991	0.525	N.C.	1.273
0.299	0.692	0.155	0.565	N.C.	N.C.
0.299	1.018	N.C.	0.788	N.C.	N.C.
0.149	0	1.070	0.801	N.C.	1.536
0.149	0.171	0.744	0.376	N.C.	1.137
0.149	0.237	0.382	0.465	2.360	0.158
0.149	0.417	0.032	0.126	2.551	0.469
0.149	0.692	0.344	0.501	3.220	0.101
0.149	1.018	0.284	0.638	3.002	N.C.
0.075	0	0.670	0.672	3.013	1.580
0.075	0.171	1.582	0.450	2.692	0.734
0.075	0.237	1.042	0.271	2.254	0.257
0.075	0.417	0.798	0.186	2.132	N.C.
0.075	0.692	0.155	0.552	2.762	0.255
0.075	1.018	0.226	0.440	2.470	0.982
0.037	0	0.418	0.315	1.505	0.580
0.037	0.171	0.877	0.288	1.433	0.617
0.037	0.237	0.605	0.321	1.542	0.210
0.037	0.417	0.214	0.491	1.484	0.133
0.037	0.692	0.226	0.486	1.227	0.220
0.037	1.018	0.118	0.500	1.774	1.271

N.C. d_e' not calculable.

TABLE 15

Experiment III (b). Gradients of log. d_e' against log. test stimulus concentration for a given adapting stimulus concentration.

	Adapting Concentration (mm. Hg).					
	0	0.17	0.24	0.42	0.69	1.02
Subject D	+0.73 (5)	+0.22 (4)	-0.22 (4)	+0.71 (5)	+0.21 (5)	+0.72 (4)
Subject E	+0.78 (5)	+0.70 (5)	+0.89 (5)	+0.47 (5)	+0.20 (5)	+0.48 (5)
Subject F	+0.45 (4)	N.C. (2)	+0.30 (4)	+0.26 (4)	+0.70 (3)	+0.20 (4)
Subject G	+0.65 (4)	+0.62 (5)	+0.95 (5)	+0.11 (3)	+0.49 (4)	N.C. (0)

Numbers in brackets indicate the number of points plotted.

TABLE 16

Experiment III (b). Gradients of log. d_e' against log. adapting stimulus concentration for a given test stimulus concentration.

	Test Concentration (mm. Hg).					
	1.19	0.60	0.30	0.15	0.08	0.04
Subject D	N.C. (0)	-0.11 (3)	-0.14 (4)	-0.43 (5)	-0.13 (5)	-0.11 (5)
Subject E	N.C. (0)	-0.80 (5)	-0.55 (5)	+0.23 (5)	+0.16 (5)	+0.33 (5)
Subject F	N.C. (0)	N.C. (2)	N.C. (2)	+0.20 (4)	0.00 (5)	+0.03 (5)
Subject G	N.C. (0)	-0.90 (3)	-0.46 (3)	-0.12 (4)	-0.57 (3)	-0.68 (4)

Numbers in brackets indicate the number of points plotted.

Discussion

There do not appear to be any overall trends evident in the data of Table 15 and Table 16. There is no justification for assigning a particular gradient to a plot of log. d_e' against either log. adapting stimulus concentration or log. test stimulus concentration. This may be due to the relatively small number of trials undergone by Ss or lack of standardization of environmental variables over sessions.

It is obvious that the method of multiple stimulus concentration presentation in a testing session has again yielded more useful data than the single concentration presentation as in Stage 1 of Experiment IId. It might have been possible to attain greater consistency and more meaningful relationships in the data if a greater number

of trials per adapting concentration had been used.

An examination of FPR reveals that Subjects D and G showed high FPR while Subject F was consistently low. An inverse relationship between FPR and adapting stimulus concentration was evident in the case of Subject E. It is not known whether the latter point is significant but Subject F's low FPR resulted in four occasions when insufficient data was available for calculation of gradients. This effect also occured in Experiment IId when Subject F encountered high intensity stimuli. It would appear that there is a need to individualize the test concentration range if multiple concentrations are to be presented in a single session.

ABILITY AND PERSONALITY TEST RESULTS

Personality profiles are shown in Appendix V and ability test results appear in Table 17.

TABLE 17

Ability Test Results. I.Q. Scores.

	AL	AQ	Combined AL & AQ
Subject A	107	124	117
Subject B	111	119	115
Subject C	105	102	104
Subject D	132	119	125
Subject E	135+	121	129
Subject F	124	119	123
Subject G	122	123	124

No attempt was made to relate personality factors and ability scores to performance except in very exceptional circumstances where it was obvious that relationship existed (Chapter 8).

GENERAL DISCUSSION OF RESULTS OF EXPERIMENTS

The individual differences in the responses of Ss to olfactory stimuli is most marked in the present study. It is not always possible to cater for these differences when two or more Ss are tested individually and simultaneously with the same stimulus source. The result is that some Ss give responses which are not capable of yielding sensitivity measures. The intervention of E with a view to modifying S's pattern of responses is of dubious benefit in that S's expectations of "correct" decision-making procedures may be such that an artificial FPR results which casts doubts on the validity of derived sensitivity measures. This was well illustrated in the case of Subject B in Experiment I.

The wide scatter of points in Fig. 16, 17 and 18 is indicative of the effects of long term testing using aqueous solutions of odorous stimuli which are particularly susceptible to contamination. The results of sessions "7" and "8" in Experiment I underline this effect and point to a possible long term change in subject sensitivity.

The use of multiple test concentrations within a single test session yields an adequate amount of data and is superior in this respect to the single test concentration presentation in a test session. This technique is worthy of further investigation.

No evidence of a consistent relationship between stimulus intensity and subject sensitivity was found in any experiment except in the case of Subjects D, E and G in Stage 2 of Experiment IId. This is in marked contrast to the results of Cheesman and Mayne.

In summary, the points made above reveal the necessity for adequate stimulus control and presentation. There is also a need for a sensitivity measure which has all the advantages of the parametric measures of signal detectability theory yet can be generated by use

of a minimum number of trials in a test session involving the presentations of multiple stimulus concentrations.

CHAPTER 8

CHAPTER 8.

DISCUSSION AND CONCLUSIONS

The nature of the results is such that an overall preference for one olfactometric technique cannot be made. This is because of the variability of subject responses over time, the limited number of subjects employed and the restricted range of conditions considered. Thus the comparison of methodology, as expressed in the aims, consists of an examination of specific advantages or otherwise of one approach over the other within the context of this programme.

DISCUSSION

The results of Experiment I indicate practice and learning effects. Subjects A, C, F and G quickly reached stability of response while Subjects B, E and D initially adopted extreme criteria of positive response (Appendix III, Tables A, B, C an Appendix IV, Tables A, B, C, D). It may be recalled that Panel X subjects (sniff-bottle method) did not use the adapting odour smelling point in simple threshold determinations until later in the programme. The marked deviation of thresholds in sessions "7" and "8" from previous sessions suggests that either subjects had to learn a new mode of response and that two sessions were not long enough to attain stability of response or that the boiled tap water in the adapting smelling point was sufficiently different from the test room background odour to influence sensitivity. The individualistic nature of the subjects' responses was shown in the thresholds obtained by Panel Y subjects (Table 4). Subject D's results are of particular interest in that three of the six threshold determinations could not be calculated

due to the sudden cut-off which she adopted. The low FPR which she exhibited was not repeated by Subject E who used the same smelling points. It is unlikely, therefore, that factors involved in stimulus presentation could account for this behaviour, rather it reflects personal characteristics such as a rapid sequencing of operations or inadequate depth of sniff which could result in "misses" and a depressed FPR. This could be related to her personality profile (Appendix V, Fig. D.) in which factors relating to degree of certainty (Q_3 and G) are low and the timidity factor (O) is high. However the interpretation of personality profiles is partly subjective in nature with a consideration of the total profile rather than individual traits leading to greatest reliability of assessment.

Subjects were not informed of the frequency ratio of "signal presence" : "signal absence" in Experiment I. Some may have expected a lower ratio than the 0.75 : 0.25 ratio used. In addition, the position of the threshold in the binary series would be individual thus producing a quasi - signal probability which was outside E's control. Informing subjects of the signal probability (as in the Signal Detectability experiments) could have helped subjects to achieve stability more readily. Similarly feedback of correctness of responses to the subject could have reduced the time S gave to learning although recent evidence casts doubt on its effectiveness (McNicol, 1973).

There is insufficient data to compare the thresholds of Subject F, a smoker, with non-smoking subjects but it would appear that, at a saturator temperature of $-12^{\circ}C$. he is at least as sensitive as other subjects.

Experiment II was used as a pilot study in the case of Panel X subjects and it was impossible to make any conclusions concerning sensitivity - concentration relationships because of the limited range

of concentrations used. Subject B was the only subject who gave results in the expected direction (Appendix III, Table E) and all at a supposedly subthreshold level of concentration. A possible explanation may be that his threshold values in Experiment I were not valid (it will be recalled that these were obtained after E's intervention) and that a practice effect resulted in a decrease in threshold value relative to adapting odour concentration despite the maintenance of FPR above the criterion of Experiment I.

As can be seen in Appendix IV, Tables E, F, G and H, Panel Y subjects (air-dilution technique) were reluctant to use all categories of response when odour concentration was beyond about ten times threshold concentration. This contrasts with Semb's subjects (Semb, 1968) who made full use of categories beyond the ten times threshold concentration. A methodological difference existed in Semb's experiments in that he paid subjects on the outcome of their performances thus motivating them to obey E's instructions concerning the full use of all categories of response. The present study did not include "payment by results" since it was thought that it would emphasise some aspects of O's decision-making processes e.g. the gambler's fallacy. Hence only a few points could be plotted on the log. d_e' - log. concentration graphs.

The multiple stimulus concentration presentation experiments reported in Experiments IIIb results (Table 14) are generally more consistent than the single stimulus presentation experiments (Table 6). This is partly because the stimulus concentration range was extended downwards to include two lower concentrations(0.075 mm. Hg and 0.037 mm. Hg) in which subjects willingly used all categories of response. It also seems reasonable to assume that the inclusion of a wide range of stimulus concentrations within a single testing session would serve to encourage S to use all categories of response.

The consistently low gradients obtained with the single stimulus concentration per session contrast with the high gradients evident in the multiple stimulus presentation experiments (Tables 7 and 15). This suggests a methodological effect, the former values being close to 0.3 obtained by Semb using n-butanol as stimulus (Semb, 1968). Thus the proposition of the olfactory transducer acting as a sensory compressor (Reese and Stevens, 1960) was not upheld in the multiple presentation experiments. FPR was similar in the two methods for all subjects except Subject C who displayed an elevated FPR in the multiple stimulus presentations. The values of d_e' near threshold concentration (0.149 mm. Hg) are higher than the expected zero ($d_e' = 0.0$ at $p = 0.50$), possibly because subjects had not stabilized at the new saturator temperature of $-12^{\circ}C$. (Table 6).

The results of Experiment IIIa (Tables 10 and 3) are not as consistent as the corresponding results of Mayne (1953) where in all cases of co-adaptation measurement a gradient of 0.7 was obtained when log. test threshold was plotted against log. adapting odour concentration. In the present study, the probability of attaining linearity was reduced by the comparatively large number of points plotted and the wide range of adapting odour concentration. In addition, the uncertainty of Subject B in making judgments limited the reliability of his results.

The 0.71 gradient of the straight line graph in Fig. 16 is close to the 0.68 value obtained by Mayne. That a facilitatory effect should be observed beyond the fifteen times threshold adapting odour concentration suggests that either an arousal effect is produced, perhaps via the reticular activating system, or that Subject A is adopting a different decision strategy.

The two unadapted thresholds for Subject B were well into the range of adapting odour concentrations used, hence points B/35a to B/10b

in Fig. 17 are subthreshold. However in view of Subject B's change in criterion it is difficult to say with certainty whether the two unadapted thresholds are reliable. If points B/8c and B/39, 40 be omitted as well as all "subthreshold" points a gradient of 0.61 is obtained. Inclusion of points B/8c and B/39, 40 yield a slope of 1.54. Thus no overall adaptation effects can be stated, there being a random distribution of points.

The gradient of 0.30 in Fig. 18 is nearer to Cheesman's value of 0.48 than to Mayne's 0.68. Point C/15, 16 is 0.7 log. units removed from the calculated regression line otherwise the points are reasonably distributed.

Mayne (1953) has not attempted to explain theoretically why a gradient of 0.7 should be obtained in all cases of co-adaptation. That a power function should exist, although intuitively attractive, is not yet supported by any theory of the olfactory observer. Moreover the function cannot cope with the limiting case where adapting odour concentration is zero i.e. simple threshold, nor does it appear to operate at suprathreshold intensities which are outside the 10 - 15 times threshold range.

The prediction that test odour concentration is an important factor in adaptation studies which use Signal Detectability sensitivity measures was confirmed in Experiment IIIb Table 16 except for Subject D where a gradient of -0.11 to -0.14 was obtained for four out of five test concentrations. Subjects D and F have gradients of -0.14 and -0.12 near threshold concentration (0.30 mm. Hg and 0.15 mm. Hg respectively). Subject E may have a similar gradient in this region since the gradient changes from +0.23 at 0.15 mm. Hg to -0.55 at 0.30 mm. Hg. The existence of positive gradients for subthreshold test concentrations in the case of Subject E may be artifactual considering the small number of trials used to calculate d_e'. A high test concentration (above ten times

threshold concentration) tended to result in the sensitivity measure not being calculable even when adapting odour concentration was matched to test concentration. This effect was most marked in Subject F who continued to use a limited number of response categories even when test odour concentration was near the threshold obtained in Experiment I. It seems likely that Subject F may have been using visual cues to "improve" his performance since FPR was consistently low and gradients close to zero (Table 16).

There is no consistent change in gradient of the log. d_e' - log. test stimulus plot with change in adapting odour concentration. Gradients range from 0.11 to 0.95 (excluding the negative gradient of -0.22). Fifteen of the 18 gradients are less than the gradients obtained under non-adapting conditions, the remainder pointing to a facilitatory effect of the adapting stimulus.

General Considerations

A direct comparison of the relative efficiency of the sniff-bottle technique and the air-dilution technique of stimulus presentation was not possible since Panel X subjects, who were originally scheduled for both sniff-bottle and air-dilution experiments, were not available for the latter.

The wide scatter of some of the results probably arises from a combination of subject and stimulus variability and factors relating to presentation techniques. An over-riding consideration is the relatively slow rate at which olfactory testing may proceed if adaptation effects of stimulus presentation are to be allowed for. Changes in subject and stimulus characteristics and in environmental conditions result in E having less control over the experimental situation than in corresponding visual or auditory experiments where a high rate of stimulus presentation

can be maintained. Moveover, results of testing sessions will inevitably have to be combined to produce sufficient numbers of trials for analysis. This has been shown to be a doubtful validity (Table11).

Individual differences in threshold, d_e' and FPR are marked except in Experiment II where there is a reasonable accordance of gradients between subjects. The restricted use of rating categories and the low criterion of positive response in the threshold experiments have resulted in valuable testing time and potential results being lost and thus forcing conclusions from insufficient data.

The order of presentation of stimuli is known to affect subject responses to stimuli (Smith, 1961). Although an attempt at controlling sequence effects was made by having three different random presentation series and keeping similar consecutive stimulus presentations to a minimum, some subjects may have been influenced by severe changes of concentration within a series.

The ideal testing environment is one which is free from background odour contamination as is physically possible. The use of an isolated air conditioning system for both test room and laboratory is probably as close as one can get to impurity-free conditions, yet some purifiers which are acclaimed to produce odour-free environments are not suitable for use in the olfaction laboratory where subjects must make fine discriminations between intensities and qualities of odours. In the present experiments few facilities were available for control of environmental factors. The proximity of the test room to chemical laboratories and their accompanying intense odours made for non-uniformity of background odour over sessions.

The temperature and humidity of the environment is an important consideration in the sniff-bottle method since vapour pressure changes, hence concentration changes, may result from significant changes in temp-

erature. The mean operating temperature of about 19°C. is satisfactory for olfactory experiments, but the standard deviation of nearly 2°C. is probably too high to ensure stable conditions both as regards aqueous solution concentration and level of subject arousal.

Contamination of aqueous solutions, especially adapting solutions is a likely source of error. The bottle cleaning procedures followed closely those devised by Mayne (1953). After every three sessions (900 trials) a new set of bottles was prepared. This meant that each bottle cap was lifted 75 times by three different subjects. Subjects did not have to handle bottles, which were fixed, but on two occasions bottles containing adapting odour solutions were replaced as they seemed to have acquired a foreign odour. These bottles were particularly susceptible to contamination and evaporation effects because their caps were lifted at the commencement of every trial i.e. 12 times more frequently than test bottle caps.

It was impossible to ensure that subjects refrained from eating for one hour prior to the testing sessions. During the 5 minute breaks subjects sometimes wished to leave the testroom and were in contact with stray odours such as tobacco smoke. Subject F was asked to remove after-shave lotion on two occasions.

Subject D had a 25-day menstrual cycle. On those test days prior to the onset of menstruation either no significant difference in sensitivity was noted (D/21b) or conflicting differences (D/18c, D/27a), compared to equivalent tests, were obtained. An elevated FPR was evidenced in two out of three tests (D/16c, D/31b) given on the twelfth day of the cycle. This may reflect a tendency towards boredom near the end of the programme rather than a biological effect.

A serious methodological defect concerns the uncertainty of the time interval between the adapting odour and test odour presentations

in Experiment III. Recovery curves (Köster, 1965) show that there is an initial rapid recovery phase after the adapting stimulus is removed so that even a minor variation in the subject's sequencing of events could alter his reaction to the test stimulus. This is more amenable to measurement, and hence control, than the sniff rate.

CONCLUSIONS

It is apparent that the approach taken to olfactory sensitivity measurement in this study is severely limited by the slow rate of presentation of stimuli. This is especially so in individual testing where fatigue, practice and boredom effects are emphasised in long sessions. Some experimenters doubt the practicability of utilizing the Signal Detectability model in olfaction and have preferred to use some form of threshold measure which keeps subject bias to a low level and the number of trials manageable e.g. a forced choice modification of constant stimulus methods (Koeleger and Köster, 1973). The present study has shown that Signal Detectability methods are workable in some subjects under certain conditions such as multiple stimulus concentration presentations in a non-adaptive environment. The smaller number of trials on which a signal occur may be sufficient to yield stable measures of the sensitivity index d_e' under these conditions, but is unlikely that this will be the case at low subjective intensities such as low test concentration or high levels of adaptation. An alternative approach may be to use group measures obtained by highly practiced subjects with high control of inter subject variables.

The wide variation in subject response in experiments utilizing the sniff-bottle method points to the vulnerability of this method to contamination effects. It has been suggested that this technique of stimulus presentation is suitable for qualitative work only (Stone, 1963b).

If this is so the simplicity of odour presentation is lost, the more elaborate and expensive air-dilution olfactometer being the only other major form of presentation at present.

No method is free from the possibility of environmental or background contamination. This aspect of the programme was undoubtedly the least to receive adequate attention and has contributed to the inconsistency of results to an unknown extent. It underlines the importance of considering sources of variation in olfactometric studies. It also prevents an answer being given to the second aim of the study viz. the bearing of methodology on the Zwaardemaker-Cheesman-Mayne hypothesis that adaptation data may be used as a basis for odour classification.

Since it is unlikely that any one molecular parameter will account for olfactory sensitivity and discriminability (Pfaffman, 1956; Cain, 1971), the building up of a classification of odours which is independent of molecular characteristics and based on a psychophysical approach is valid. It remains for olfactometrists to develop a methodology that is suitable for adaptive and non-adaptive conditions and which allows for subject variables such as response bias to be taken into consideration. The method, (or combination of methods) finally developed will be able to cope with the prolonged adapting effects of odour presentations given the fine degree of control of stimulus purity and environmental variables which the quantitative study of olfaction demands.

REFERENCES

REFERENCES

ADRIAN, E.D. The basis of sensation. British Medical Journal, 1954, 1, 287-290.

ADRIAN, E.D. The electrical activity of the mammalian olfactory bulb. Electroencephalography and Clinical Neurophysiology, 1950, 2, 377-388.

AMIROV, R.Z. Effect of subthreshold olfactory stimuli on the sensitivity of the sense of smell in normal and pathological conditions. Report to the Moscow Section of the Society of Physiologists, Moscow, 1954.

AMOORE, J.E. Current status of the steric theory of odor. Annals of the New York Academy of Sciences, 1964, 116, 457-476.

AMOORE, J.E. Stereochemical theory of olfaction. Nature, 1963, 198, 271-272.

AMOORE, J.E. The stereochemical specificities of human olfactory receptors. Perfumery and Essential Oils Record, 1952, 43, 321-323.

AMOORE, J.E., VENSTROM, D. and NUTTING, M. Sweaty odor in fatty acids: measurements of similarity, confusion and fatigue. Journal of Food Science, 1972, 37, 33-35.

ARONSOHN, E. Experimentelle Untersuchungen zur physiologie des geruchs. Archiv fur Anatomie und Physiologie, 1886, Physiol Abt. 321-357. Cited by Mayne, 1953.

BAILEY, E.H.S. and NICHOLS, E.L. Preliminary notes on the delicacy of the special senses. New York Medical Journal, 1884, 40, 325.

BAUER, J.W., SQUIRES, K.C. and LINDSAY, P.H. Computer signal detection by monitoring auditory evoked potentials. Perception and Psychophysics, 1972, 11 (4), 301-308.

BECK, L.H., KRUGER, L. and CALABRESI, P. Observations on olfactory intensity I. Training procedure, methods and data for two aliphatic homologous series. Annals of the New York Academy of Sciences, 1954, 58, 225-238.

BÉKÉSY, G. von, Experiments in hearing, New York: McGraw-Hill, 1960.

BERGLUND, B., BERGLUND, U., ENGEN, T. and EKMAN, G. Multidimensional analysis of 21 odors. Reports from the Psychological Laboratories, The University of Stockholm, 1972, No. 345.

BERGLUND, B., BERGLUND, U, ENGEN, T. and LINDVALL, T. The effect of adaptation on odor detection. Perception and Psychophysics, 1971, 9 (5), 435-438.

BERKELEY (LORD) and HARTLEY, E.G.J. Osmotic pressures of aqueous solutions. Philosophical Transactions, 1908, A 209, 177-203.

BLACKWELL, H.R. Psychophysical thresholds: experimental studies of methods of measurement. Bulletin of the Electronic Research Institute of the University of Michigan, 1953, Number 36, Ann Arbor: University of Michigan Press.

BROWN, K.S., MACLEAN, C.M. and ROBINETTE, R.R. The distribution of the sensitivity to chemical odors in man. Human Biology, 1968, 40 (4), 456-472.

CAIN, W.S. Physicochemical characteristics and supraliminal odor intensity: Reply to Mitchell. Perception and Psychophysics, 1971, 9, 478-479.

CAIN, W.S. and ENGEN, T. Olfactory adaptation and the scaling of odor intensity. In: C. Pfaffman (Ed.), Olfaction and Taste III, 1969, New York: Rockefeller University Press.

CATTELL, R.B. The 16 Personality Factor Test, Form C. Institute for Personality and Ability Testing, 1602 Coronado Drive, Champaign, Illinois, U.S.A., 1965.

CHEESMAN, G.H. Measuring group olfactory thresholds. Soap, Perfumery and Cosmetics, 1955, 28, 1395-1398.

CHEESMAN, G.H. Progress in odour research: Pira report. Leatherhead, Surrey: The Research Association for the Paper and Board Printing and Packaging Industries, 1972.

CHEESMAN, G.H. and KIRKBY, H.M. An air dilution olfactometer suitable for group threshold measurements. Quarterly Journal of Experimental Psychology, 1959, 11 (2), 115-123.

CHEESMAN, G.H., and MAYNE, S. The influence of adaptation on absolute threshold measurements for olfactory stimuli. Quarterly Journal of Experimental Psychology, 1953, 5, 22-30.

CHEESMAN, G.H., and TOWNSEND, M.J. Further studies on the olfactory thresholds of pure chemical substances, using the "Sniff-Bottle Method". Quarterly Journal of Experimental Psychology, 1956, 8, 8-14.

COMFORT, A. Communication may be odorous. New Scientist and Science Journal, 25th February, 1971.

CORBIT, T.E. Facilitation of olfactory signal detection by cross-adaptation. Unpublished PH.D. Thesis, Brown University, 1969.

CORBIT, T.E., and ENGEN, T. Facilitation of olfactory detection. Perception and Psychophysics, 1971, 10, 433-436.

CORNSWEET, T.N. The staircase method in psychophysics. American Journal of Psychology, 1962, 75, 485-491.

CORSO, J.F. A theoretico-historical review of the threshold concept. Psychological Bulletin, 1963, 60, 356-370.

EGAN, J.P., SCHULMAN, A.I., and GREENBERG, G.Z. Operating characteristics determined by binary decisions and by ratings. Journal of the Acoustical Society of America, 1959, 31, 768-773.

EKMAN, G., BERGLUND, B., BERGLUND, U., and LINDVALL, T. Perceived intensity of odor as a function of time of adaptation. Scandinavian Journal of Psychology, 1967, 8, 177-186.

ELSBERG, C.A. The Sense of Smell XIV. The relation of the cerebral cortex to the olfactory impulse and the areas of the brain involved in fatigue of the sense of smell. Bulletin of the Neurological Institute of New York, 1936, 6, 118-125.

ELSBERG, C.A., LEVY, I., and BREWER, E.D. The Sense of Smell I. A new and simple method of quantitative olfactometry. Bulletin of the Neurological Institute of New York, 1935, 4, 5-19. (a)

ELSBERG, C.A., LEVY, I., and BREWER, E.D. The Sense of Smell V. The relative importance of volume and pressure of impulse for the sensation of smell and the nature of the olfactory process. Bulletin of the Neurological Institute of New York, 1935, 4, 264-269. (b)

EMMERICH, D.S. ROCs obtained with two signal intensities presented in random order, and a comparison between yes-no and rating ROCs. Perception and Psychophysics, 1968, 3,(1a), 35-40.

ENGEN, T. Cross-adaptation to the aliphatic alcohols. American Journal of Psychology, 1963, 76, 96-102.

ENGEN, T. Effect of practice and instruction on olfactory thresholds. Perceptual and Motor Skills, 1960, 10, 195-198.

ENGEN, T. Psychophysical scaling of odor intensity and quality. Annals of the New York Academy of Sciences, 1964, 116, 504-516.

ENGEN, T., and BOSACK, T.N. Facilitation in olfactory detection. Journal of Comparative and Physiological Psychology, 1969, 68, 320-326.

ENGEN, T., and PFAFFMANN, C. Absolute judgment of odor intensity. Journal of Experimental Psychology, 1959, 58, 23-26.

FERNBERGER, S.W. Instructions and the psychophysical limen. American Journal of Psychology, 1931, 43, 361-377.

FINNEY, D.J. Probit Analysis. Cambridge, 1952.

FREY, A.H. Electrical charge distribution and olfactory methodology and theory. Psychological Bulletin, 1968, 69 (6), 390-395.

FRIEDMAN, M.P. The role of learning in olfactory sensitivity. Dissertation Abstracts, 1960, 20 (9), 3853- 3854.

FURCHTGOTT, E., and FRIEDMAN, M.P. The effects of hunger on taste and odor RLs. Journal of Comparative and Physiological Psychology, 1960, 53, 576-581.

GOETZL, F.R., ABEL, M.S., and AHOKAS, A.J. Occurrence in normal individuals of diurnal variations in olfactory acuity. Journal of Applied Psychology, 1950, 2, 553-562.

GOETZL, F.R., and STONE, F. The influence of amphetamine sulfate upon olfactory acuity and appetite. Gastroenterology, 1948, 10, 708-713.

GREEN, D.M., and SWETS, J.A. Signal detection theory and psychophysics. New York: Wiley, 1966.

GREGSON, R.A.M., MITCHELL, M.J., SIMONDS, M.B., and WELLS, J.E. Relative olfactory intensity perception mediated by ratio-range category scale responses. Perception and Psychophysics, 1969, 6 (3), 133-136.

GRUNDVIG, J.L., DUNSTMAN, R.E., and BECK, E.C. The relationship of olfactory receptor stimulation to stimulus-environmental temperature. Experimental Neurology, 1967, 18, 416-428.

GUILD, A.A. Olfactory acuity in normal and obese human subjects: diurnal variations and the effect of d-amphetamine sulphate. Journal of Laryngology and Otology, 1956, 70, (7), 408-414.

GUNDLACH, R.H., and KENWAY, G. A method for the determination of olfactory thresholds in humans. Journal of Experimental Psychology, 1939, 24, 192-201.

HELMHOLTZ, H.L.F. von. Handbuch der physiolo gischen Optik. (1st. edition). Hamburg and Leipzig: Voss, 1866.

HELMHOLTZ, H.L.F. von. On the theory of compound colours. Philosophy Magazine, 1852, 4, 519-534.

HINCHCLIFFE, R. Aging and Sensory Thresholds. Journal of Gerentology, 1962, 17, 45-50.

JANOWITZ, H.D., and GROSSMAN, M.I. Gusto-olfactory thresholds in relation to appetite and hunger sensations. Journal of Applied Physiology, 1949, 2 (4), 217-222.

JONES, F.M. An analysis of individual differences in olfactory thresholds. American Journal of Psychology, 1957, 70, 227-232.

KOELEGA, H.S., and KÖSTER, E.P. Some experiments on sex differences in odor perception. Paper presented at Conference on Odors: Evaluation, Utilization and Control. New York Academy of Sciences, October 2nd, 1973.

KÖSTER, E.P. Adaptation, recovery and specificity of olfactory receptors. Revue de Laryngologie, 1965, 86, 880-894.

Le MAGNEN, J. Les phénomènes olfacto-sexuels chez l'homme. Archives des Sciences Physiologiques, 1952, 6, 125-160.

LINKER, E., MOORE, M.E., and GALANTER, E. Taste thresholds, detection models and disparite results. Journal of Experimental Psychology, 1964, 67, 59-66.

LIPSITT, L.P., ENGEN, T., and KAYE, H. Developmental changes in the olfactory threshold of the neonate. Child Development, 1963, 34, 371-376.

LUCE, R.D. A threshold theory for simple detection experiments. Psychological Review, 1963a, 70, 61-79.

LUCE, R.D. Detection and Recognition, in LUCE, R.D., BUSH, R.R., and GALANTER, E. (Eds), Handbook of Mathematical Psychology. New York: Wiley, 1963b.

LUCE, R.D. Detection thresholds: a problem reconsidered. Science, 1960, 132, 1495.

McNICOL, D. A primer of signal detection theory. London: George Allen and Unwin, 1972.

McNICOL, D. Feedback as a source of information and as a source of noise in discriminations. Paper presented at the Eighth Annual Conference of the Australian Psychological Society, Sydney, 1973.

MARKOWITZ, J., and SWETS, J.A. Factors affecting the slope of empirical ROC curves: comparison of binary and rating responses. Perception and Psychophysics, 1967, 2, 91-97.

MAYNE, S. Determination of olfactory thresholds for pure chemical substances. Unpublished PH.D. Thesis, Reading University, 1953.

MITCHELL, M.J. Some psychological aspects of the chemical senses. Unpublished PH.D. Dissertation, University of Canterbury, 1971.

MITCHELL, M.J., and McBRIDE, R.L. Effects of propanol masking odor on the olfactory intensity scaling of eugenol. Journal of Experimental Psychology, 1971, 87 (3), 309-313.

MONCRIEFF, R.W. A technique for comparing the threshold concentrations for olfactory, trigeminal, and ocular irritations. Quarterly Journal of Experimental Psychology, 1955, 7, 128-132.

MONCRIEFF, R.W. Olfaction - a comparison of homogeneous and heterogeneous adaptation. Manufacturing Chemist, January, 1959.

MONCRIEFF, R.W. Olfactory adaptation and odour likeness. Journal of Physiology, 1956, 133, 301-316.

MONCRIEFF, R.W. The Chemical Senses. John Wiley and Sons, New York, 1944.

MULVANEY, B.D. and HEIST, H.E. Mapping of rabbit olfactory cells. Journal of Anatomy, 1970, 107 (1), 19-30.

MURRAY, B., and CAMPBELL, D. Differences between olfactory thresholds in two sleep states in the newborn infant. Psychonomic Science, 1970, 18 (6), 313-314.

OTTOSON, D. Analysis of the electrical activity of the olfactory epithelium. Acta Physiologica Scandinavica, 1956 (Supplementum 122). 35, 1-83.

OUGH, C.S. and STONE, H. An olfactometer for rapid and critical odor measurements. Journal of Food Science, 1961, 26, 452-456.

PANGBORN, R.M., BERG, H.W., ROESSLER, E.B. and WEBB, A.D. Influence of methodology on olfactory response. Perceptual and Motor Skills, 1964, 18, 91-103.

PARKES, A.S. and BRUCE, H.M. Olfactory stimuli in mammalian reproduction. Science, 1961, 134, 1049-1054.

PATTERSON, P.M. and LAUDER, B.A. The incidence and probable inheritance of "smell blindness". Journal of Heredity, 1948, 39, 295-297.

PETERSON, W.W., BIRDSALL, T.G. and FOX, W.C. The theory of signal detectability. Transactions of the Electronic Research Institute University of Michigan. Professional Group on Information Theory, 1954, PG IT-4, 171-212.

PFAFFMAN, C. Review for year ending May, 1955, of literature on the chemical senses. Annual Review of Psychology, 1956, 7, 391-408.

PFAFFMAN, C. Taste and Smell, In S.S. Stevens (Ed.) Handbook of Experimental Psychology, John Wiley, New York, 1951.

PRYOR, G.T., STEINMETZ, G. and STONE, H. Changes in absolute detection threshold and in subjective intensity of suprathreshold stimuli during olfactory adaptation and recovery. Perception and Psychophysics, 1970, 8, 331-335.

RAND CORPORATION. A Million Random Digits with 100,000 Normal Deviates. Glencoe Free Press, Inc., a division of The MacMillan Company, 1955

REESE, T.S. and STEVENS, S.S. Subjective intensity of coffee odor. American Journal of Psychology, 1960, 73, 424-428.

SCHNEIDER, R.A. The sense of smell in man - its physiologic basis. New England Journal of Medicine, 1967, 227 (6), 299-303.

SCHNEIDER, R.A. and WOLF, S. Olfactory perception thresholds for citral utilizing a new type olfactorium. Journal of Applied Physiology, 1955, 8, 337-342.

SEMB, G. The detectability of the odor of butanol. Perception and Psychophysics, 1968, 4,(6), 335-340.

SIEGEL, S. Nonparametric statistics for the behavioural sciences. McGraw-Hill Book Company, Inc., 1956.

SMITH, J.E.K. Stimulus programming in Psychophysics. Psychometrika, 1961, 26 (1), 27-33.

STEINMETZ, G., PRYOR, G.T. and STONE, H. Effect of blank samples on absolute odor threshold determinations. Perception and Psychophysics, 1969, 6 (3), 142-144.

STEVENS, S.S. Power-group transformations under glare, masking and recruitment. Journal of the Acoustical Society of America, 1966, 39, 725-735.

STONE, H. Factors influencing behavioural responses to odor discrimination - a review. Journal of Food Science, 1966, 31, 784-790.

STONE, H. Influence of temperature on olfactory sensitivity. Journal of Applied Physiology, 1963, 18 (4), 746-751. (a)

STONE, H. Techniques for odor measurement: olfactometric vs. sniffing. Journal of Food Science, 1963, 28, 719-725. (b)

STONE, H. and PRYOR, G.T. Some properties of the olfactory system of man. Perception and Psychophysics, 1967, 2, 516-518.

STUIVER, M. Biophysics of the sense of smell. Unpublished PH.D. Thesis, University of Groningen (the Netherlands), 1958.

SWETS, J.A. Is there a sensory threshold? Science, 1961, 134, 168-177.

SWETS, J.A., TANNER, W.P. Jr. and BIRDSALL, T.G. The evidence for a decision-making theory of visual detection. Electronic Defense Group, Technical Report No. 40, 1955, University of Michigan.

TANNER, W.P. Jr. and SWETS, J.A. A decision-making theory of visual detection. Psychological Review, 1954, 61, 401-409.

TOWNSEND, M.J. The "Sniff Bottle Method" for the determination of olfactory thresholds of pure chemical substances. Unpublished Departmental Research Report, Reading University, 1956.

TREISMAN, M. and HOWARTH, C.I. Changes in threshold level produced by a signal preceding or following the threshold stimulus. Quarterly Journal of Experimental Psychology, 1959, 11 (3), 129-142.

TREISMAN, M. and WATTS, T.R. Relation between signal detectability theory and the traditional procedures for measuring sensory thresholds: estimating d' from results given by the method of constant stimuli. Psychological Bulletin, 1966, 66 (6), 438-454.

VENSTROM, D. and AMOORE, J.E. Olfactory threshold in relation to age, sex, or smoking. Journal of Food Science, 1968, 33, 264-265.

VERPLANCK, W.S., COLLIER, G.H. and COTTON, J.W. Nonindependence of successive responses in measurements of the visual threshold. Journal of Experimental Psychology, 1952, 44, 273-282.

VIERLING, J.S. and ROCK, J. Variations in olfactory sensitivity to exaltolide during the menstrual cycle. Journal of Applied Physiology, 1967, 22 (2), 311-315.

WALSH, R.R. Single cell spike activity in the olfactory bulb. American Journal of Physiology, 1956, 186, 255-257.

WATSON, C.S., RILLING, M.E. and BOURBON, W.T. Receiver-operating characteristics determined by a mechanical analog to the rating scale. Journal of the Acoustical Society of America, 1964, 36, 283-288.

WELFORD, A.T. Ageing and human skill. Oxford: Oxford University Press, 1958.

WELFORD, A.T. The measurement of sensory-motor performance: survey and reappraisal of twelve years' progress. Ergonomics, 1960, 3, 189-230.

WENZEL, B.M. Techniques in olfactometry: a critical review of the last one hundred years. Psychological Bulletin, 1948, 45, 231-247.

WOERDEMAN, H. L'Influence de la temperature d' un gaz odorant sur la sensation olfactive. Archives neerlandaises de physiologie de l'homme et des animaux, 1934, 19, 88-93.

WRIGHT, R.H. Smells as information. New Scientist, 1964, 23, 706-709.

YOSHIDA, M. Studies in the psychometric classification of odors. Japanese Journal of Psychology, 1964, 6, 1-17.

YOUNG, T. On the theory of light and colours, 1807. In Vol. 2 of Lectures in natural philosophy. London. Printed for Joseph Johnson, St. Pauls Church Yard, by William Savage, 613-632.

ZWAARDEMAKER, H. Anosmias of Nervous Origin. Lecture given at the General Meeting of the Third Physics and Chemistry Congress at Utrecht, 4th April, 1891.

ZWAARDEMAKER, H. Die physiologie des geruchs, Leipzig, 1895.

ZWAARDEMAKER, H. L'Odorat. Paris: Doin, 1925.

ZWAARDEMAKER, H. Prazisionolfaktometrie. Archiv fur laryngologie und rhinologie, 1904, 15, 171-177.

APPENDIX I

APPENDIX I.

CHEMICAL COMPOSITION OF SAMPLES OF ISOPROPYL ALCOHOL

Suppliers: May and Baker Limited, Dagenham, England.

Quantity: 500 ml. in dark glass bottles with plastic screw-top lid.

Specifications:

Assay	Not less than 99%
Boiling Range	81°C. - 83°C.
Weight per ml.	0.783 - 0.786 g. / 20°C.
Acidity	Not more than 0.03 ml. N%
Alkalinity	Not more than 0.03 ml. N%
Aldekydes and Ketones ..	Not more than 0.1% W/V.
Water	Not more than 0.3%
Non-volatile Residue ...	Not more than 0.01%

APPENDIX II

APPENDIX II

```
      OLFACTION THRESHOLD PROBIT ANALYSIS,U379 sp;
begin integer array title[1:24];  integer i,j,k,one,nine,m,n,p,N;
      real bi,ai,xi,zi,Zsum,XXsum,XBsum,Bsum,Xsum,A,B,temp,y;
      real array a,b,g,x,z[0:9],c[0:100],d,e,f[11:89];  switch s:=L,skip,twice;
      sameline;  digits(2);  aligned(2,4);
      print $$1?Olfaction Threshold Probit Analysis, U379$12??;   one:=1;  nine:=9;
      for i:=0 step 1 until 100 do read c[i];
      for i:=11 step 1 until 50 do read d[i];
      for i:=11 step 1 until 89 do read e[i];
      for i:=11 step 1 until 50 do begin read f[i];  j:=100-i;  d[j]:=d[i];  f[j]:=f[i] end;
L:    read n;  if n<1 then print $$r5hr40??, stop;
      N:=1;  instring(title,N);  N:=1;  print $$1??, outstring(title,N), $$1??;
      for m:=1 step 1 until n do
            begin for i:=1 step 1 until 9 do begin read a[i];  z[i]:=1;  x[i]:=i-5 end;
                  for i:=1 step 1 until 9 do
                        begin read bi;  g[i]:=b[i]:=bi;  ai:=a[i];
                              if bi=0 or bi=ai then z[i]:=0
                              else  begin k:=100.0*bi/ai;
                              b[i]:=c[k]  end
                        end for i;
                  p:=1;  print $$1?CASE =?, m, $$1?Intermediate results:$1??;
                  goto skip;
      twice:      for i:=one step 1 until nine do
                        begin temp:=A*x[i]+B;  k:=10.0*temp;
                              if k<11 then begin one:=3;  k:=11;  print $$1?Lobound adj?  end;
                              if k>89 then begin nine:=7;  k:=89;  print $$1?Hibound adj?  end;
                              z[i]:=d[k]*a[i];  b[i]:=e[k]+g[i]*f[k]/a[i];

                  p:=0; end;
      skip:       Zsum:=XXsum:=XBsum:=Bsum:=Xsum:=0.0;
                  for i:=one step 1 until nine do
                        begin xi:=x[i];  zi:=z[i];  bi:=b[i];
                              Xsum:=Xsum+xi*zi;
                              Bsum:=Bsum+bi*zi;
                              XXsum:=XXsum+xi*xi*zi;
                              XBsum:=XBsum+xi*bi*zi;
                              Zsum:=Zsum+zi
                        end for i;
                  XXsum:=Zsum*XXsum-Xsum*Xsum;
                  XBsum:=Zsum*XBsum-Xsum*Bsum;
                  A:=XBsum/XXsum;  Xsum:=Xsum/Zsum;  Bsum:=Bsum/Zsum;
                  B:=Bsum-A*Xsum;
                  print $$t?A =?, A, $   B =?, B;
                  if p=1 then goto twice;
                  temp:=Xsum;  Xsum:=(5.0-B)/A;  XXsum:=XXsum/Zsum;
                  y:=1.0/(A*A*Zsum*XXsum);
                  y:=y*(XXsum+Zsum*Xsum*Xsum+Zsum*temp*temp-2.0*Zsum*Xsum*temp);
                  print $$1?Main results:$1t?THRESHOLD =?, special(2), Xsum;
                  print $$t?STAN.DEV =?, sqrt(y), $$r81??;
                  one:=1;
                  nine:=9;
            end for m loop;
      goto L;

end of program;
```

```
    D
* WR
C-8K PHYS. CHEM.  FOCAL 73 !

01.01 T "LINEAR LEAST SQUARE FIT",!!
01.02 A "NUMBER OF DATA PAIRS "M
01.03 S X=0; S Y=0; S XX=0; S XY=0;
01.04 T !"INPUT DATA PAIRS, X FIRST -"
01.05 F I=1,M; D 2
01.06 S SL=(M*XY-X*Y)/(M*XX-X*X)
01.07 S CN=(Y-SL*X)/M
01.08 T !!,%,"SLOPE"SL,"    INTERCEPT"CN,!
01.09 Q

02.01 T !,%2,"ITEM"I,"  XI "; A XI; T "  YI "; A YI
02.02 S X=X+XI; S Y=Y+YI; S XX=XX+XI*XI; S XY=XY+XI*YI
*
```

APPENDIX III

TABLE A.

EXPERIMENT I RESULTS. SUBJECT A.

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
A/3c	9.368	-	-	0.306	-2.514	-2.352 -2.677	0.143	18
A/4a	9.368	-	-	0.381	-2.419	-2.331 -2.534	0.048	20
A/5b	7.621	-	-	0.226	-2.646	-2.503 -2.790	0.128	18
A/6c	7.921	-	-	0.236	-2.627	-2.465 -2.899	0.128	21
A/7a	8.275	-	-	0.204	-2.690	-2.543 -2.838	0.143	20
A/8b	8.275	-	-	0.232	-2.635	-2.475 -2.793	0.016	17
A/39c	15.99	Boiled Tap Water	-	1.377	-1.807	-1.759 -1.963	0	21

TABLE B.

EXPERIMENT I RESULTS. SUBJECT B.

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour	Log. Adapt. Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
B/6a	8.275	-	-	2.604	-1.584	-1.476 -1.692	0	20
B/7b	8.489	-	-	2.745	-1.561	-1.444 -1.679	0	14
B/30b	16.01	Boiled Tap Water	-	0.580	-2.237	-2.138 -2.336	0	16
B/36b	15.99	Boiled Tap Water	-	0.959	-2.018	-1.917 -2.119	0.016	22

TABLE C.

EXPERIMENT I RESULTS. SUBJECT C.

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
C/3c	8.179	-	-	1.799	-1.745	-1.564 -1.927	0.080	24
C/4a	8.179	-	-	2.235	-1.651	-1.479 -1.804	0	20
C/5b	7.621	-	-	0.910	-2.041	-1.903 -2.179	0.143	20
C/6c	7.921	-	-	2.136	-1.670	-1.555 -1.786	0	19
C/7a	8.489	-	-	0.239	-2.622	-2.476 -2.769	0.143	19
C/8b	8.489	-	-	0.764	-2.117	-2.017 -2.217	0.016	18
C/34b	16.01	Boiled Tap Water	-	1.658	-1.780	-1.686 -1.874	0.048	24
C/40b	15.99	Boiled Tap Water	-	1.752	-1.756	-1.666 -1.846	0.048	20

TABLE D.

EXPERIMENT II RESULTS. SUBJECT A.

Case	Test Concn. ($M \times 10^{-2}$)	Log.Test Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
A/23b	0.366	-2.437	3.545	0.550	1.075	0.020	23
A/25a	0.392	-2.406	2.709	0.433	0.487	0.032	20
*A/27c	0.392	-2.406	0.287	-0.543	1.014	0.076	19
A/19c	0.980	-2.009	2.738	0.438	1.414	0.056	21
A/17a	1.141	-1.943	2.756	0.440	1.284	0.061	19
A/21c	1.475	-1.831	3.073	0.488	0.557	0.048	20

* repeat test designed to investigate ageing effects of stimulus material. Results not included in calculations.

TABLE E.

EXPERIMENT II RESULTS. SUBJECT B.

Case	Test Concn. ($M \times 10^{-2}$)	Log.Test Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
B/20c	0.366	-2.437	2.065	0.315	0.777	0.124	20
*B/23c	0.392	-2.406	2.656	0.424	1.053	0.060	17
B/15c	0.980	-2.009	2.685	0.429	0.543	0.048	21
*B/17c	0.980	-2.009	2.515	0.401	1.195	0.119	18
B/18a	1.475	-1.831	2.601	0.415	0.888	0.132	17

* repeat tests.

TABLE F.

EXPERIMENT II RESULTS. SUBJECT C.

Case	Test Concn. ($M \times 10^{-2}$)	Log.Test Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
C/22a	0.366	-2.437	3.495	0.544	0.416	0.032	18
C/24c	0.392	-2.406	3.103	0.492	0.797	0.028	19
*C/26b	0.392	-2.406	2.901	0.463	1.125	0.032	18
C/19a	0.980	-2.009	3.470	0.540	0.906	0.008	21
C/17b	1.141	-1.943	2.882	0.460	1.180	0.016	19

* repeat test.

TABLE G.

EXPERIMENT III (a) RESULTS. SUBJECT A.

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log. Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
A/9c	16.75	8.375	-1.077	0.925	-2.034	-1.896 -2.172	0.127	20
A/10a	16.75	8.375	-1.077	0.771	-2.113	-1.983 -2.243	0.127	18
A/11b	15.60	1.950	-1.710	1.640	-1.785	-1.672 -1.898	0.063	18
A/12c	15.60	1.950	-1.710	1.014	-1.994	-1.901 -2.087	0.016	17
A/13a	16.29	1.018	-1.992	1.098	-1.959	-1.858 -2.061	0	16
A/14b	16.29	1.018	-1.992	0.893	-2.049	-1.947 -2.150	0.016	17
A/15a	15.13	7.565	-1.121	1.114	-1.953	-1.854 -2.044	0	22

TABLE G.

EXPERIMENT III (a) RESULTS. SUBJECT A. (Cont'd)

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
A/16c	15.13	7.565	-1.121	0.834	-2.079	-1.971 -2.185	0	22
A/38b	16.05	4.013	-1.397	1.491	-1.827	-1.725 -1.927	0.032	21
A/37a	15.74	0.580	-2.236	0.627	-2.203	-2.090 -2.321	0.048	20
A/36c	16.46	0.514	-2.289	1.872	-1.728	-1.640 -1.815	0.016	21
A/40a	16.58	6.219	-1.206	1.554	-1.809	-1.735 -1.882	0	20
A/41b	8.29	6.219	-1.206	0.815	-2.089	-2.011 -2.166	0	18
A/42c	31.64	7.910						
A/43a	31.64	7.910						

Standard Deviation of Threshold too great to allow a reliable threshold to be calculated.

TABLE H.

EXPERIMENT III (a) RESULTS. SUBJECT B.

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
B/8c	16.75	8.375	-1.077	2.866	-1.543	-1.416 -1.669	0.048	18
B/9a	15.61	7.805	-1.108	1.648	-1.783	-1.689 -1.877	0.016	18
B/10b	15.60	1.950	-1.710	2.773	-1.557	-1.461 -1.653	0.016	16
B/11c	16.29	1.018	-1.992	1.083	-1.964	-1.842 -2.087	0.063	15
B/13b	15.13	7.565	-1.121	1.312	-1.882	-1.776 -1.988	0	20
B/14c	15.68	7.840	-1.106	1.570	-1.804	-1.701 -1.908	0.016	19
B/31c	16.46	0.514	-2.289	0.544	-2.264	-2.150 -2.379	0.048	22

TABLE H.

EXPERIMENT III (a) RESULTS. SUBJECT B. (Cont'd)

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
B/32a	15.74	0.580	-2.236	0.382	-2.418	-2.309 -2.527	0.032	22
B/33b	16.05	4.013	-1.397	0.830	-2.081	-1.983 -2.179	0.032	21
B/34c	16.05	4.013	-1.397	1.166	-1.933	-1.809 -2.058	0	18
B/35a	15.97	0.249	-2.604	1.593	-1.798	-1.691 -1.905	0.032	20
B/38a	8.290	6.219	-1.206	0.911	-2.041	-1.929 -2.152	0.048	19
B/39b	31.64	7.910	-1.102	6.675	-1.176	-1.097 -1.255	0	21
B/40c	31.64	7.910	-1.102	6.105	-1.214	-1.092 -1.336	0.032	21

TABLE I.

EXPERIMENT III (a) RESULTS. SUBJECT C.

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
C/9c	15.61	7.805	-1.108	0.971	-2.013	-1.910 -2.116	0.032	18
C/10a	15.61	7.805	-1.108	1.511	-1.821	-1.689 -1.953	0	18
C/11b	16.02	1.950	-1.710	0.934	-2.030	-1.948 -2.111	0.048	17
C/12c	16.02	1.950	-1.710	1.516	-1.819	-1.718 -1.920	0	18
C/13a	15.91	0.994	-2.003	0.943	-2.025	-1.917 -2.126	0.016	18
C/14b	15.91	0.994	-2.003	1.329	-1.876	-1.762 -1.990	0	19
C/15c	15.68	7.840	-1.106	0.716	-2.145	-2.048 -2.242	0	Not record-ed.
C/16a	15.68	7.840	-1.106	0.847	-2.072	-1.978 -2.166	0	20

TABLE I.

EXPERIMENT III (a) RESULTS. SUBJECT C. (Cont'd)

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
C/35c	16.46	0.580	-2.236	1.500	-1.824	-1.729 -1.919	0.016	20
C/36a	15.74	0.580	-2.236	1.057	-1.976	-1.904 -2.048	0	20
C/37b	16.05	4.013	-1.397	1.406	-1.852	-1.759 -1.945	0	23
C/38c	16.05	4.013	-1.397	2.802	-1.553	-1.456 -1.649	0	18
C/39a	15.97	0.249	-2.604	1.471	-1.832	-1.736 -1.929	0.016	22
C/41c	16.58	6.219	-1.206	1.311	-1.882	-1.784 -1.980	0.032	19
C/42a	8.290	6.219	-1.206	2.546	-1.594	-1.477 -1.711	0	17
C/43b	31.64	7.910	-1.102	4.755	-1.323	-1.244 -1.401	0	21

TABLE J.

EXPERIMENTS I and III (a) RESULTS. SUBJECT A. (Combined Sessions)

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt. Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log. Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
A/3,4	9.368	-	-	0.343	-2.465	-2.367 -2.563	0.095	19
A/7,8	8.275	-	-	0.218	-2.663	-2.554 -2.771	0.079	18
A/9,10	16.75	8.375	-1.077	0.846	-2.073	-1.978 -2.167	0.127	19
A/11,12	15.60	1.950	-1.710	1.276	-1.894	-1.819 -1.970	0.040	17
A/13,14	16.29	1.018	-1.992	0.955	-2.020	-1.949 -2.091	0.008	16
A/15,16	15.13	7.565	-1.121	0.967	-2.015	-1.888 -2.142	0	20

TABLE K.

EXPERIMENT III (a) RESULTS. SUBJECT B. (Combined Sessions)

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
B/33,34	16.05	4.013	-1.397	0.997	-2.001	-1.922 -2.081	0.016	19
B/39,40	31.64	7.910	-1.102	5.352	-1.272	-1.200 -1.343	0.016	21

TABLE L.

EXPERIMENTS I and III (a) RESULTS. SUBJECT C. (Combined Sessions)

Case	Concn. ($M \times 10^{-2}$)	Adapt. Odour ($M \times 10^{-2}$)	Log. Adapt.Odour Concn.	Thresh. Concn. ($M \times 10^{-2}$)	Log.Thresh. Concn.	Log. Limits	FPR	Temp. ($^{o}C.$)
C/3,4	8.179	-	-	1.994	-1.700	-1.589 -1.812	0.040	22
C/7,8	8.489	-	-	0.432	-2.364	-2.273 -2.456	0.079	18
C/9,10	15.61	7.805	-1.108	1.171	-1.931	-1.852 -2.010	0.016	18
C/11,12	16.02	1.950	-1.710	1.260	-1.900	-1.833 -1.966	0.024	18
C/13,14	15.91	0.994	-2.003	1.131	-1.947	-1.869 -2.024	0.008	18
C/15,16	15.68	7.840	-1.106	0.779	-2.108	-2.041 -2.176	0	20
C/37,38	16.05	4.013	-1.397	1.889	-1.724	-1.656 -1.792	0.008	20

TABLE M.

EXPERIMENT III (b) RESULTS. SUBJECT A.

Test Stimulus 0.3261 x 10^{-2}M.

Case	Adapt.Odour Concn. (M x 10^{-2})	Log.Adapt. Odour Concn.	de'	Log.de'	N S+N	FPR	Temp. (°C.)
A/29b	1.441	-1.8412	0.913	-0.0397	0.981	0.032	19
A/30c,31a	1.441	-1.8412	1.101	0.0419	0.845	0.020	19
A/33c	0.4239	-2.3728	1.472	0.1681	0.775	0.028	17
	Test Stimulus 1.186 x 10^{-2}M.						
A/30c,31a	1.441	-1.8412	2.692	0.4300	0.724	0.020	19
A/33c	0.4239	-2.3728	2.205	0.3433	0.797	0.028	17

TABLE N.

EXPERIMENT III (b) RESULTS. SUBJECT B.

Test Stimulus 0.3261 x 10^{-2}M.

Case	Adapt.Odour Concn. (M x 10^{-2})	Log.Adapt. Odour Concn.	de'	Log.de'	N S+N	FPR	Temp. (°C.)
B/25b	1.441	-1.8412	0.970	-0.0132	0.791	0.318	15
B/26c	0.8766	-2.0572	0.810	-0.0914	0.802	0.203	18
B/28b	0.4239	-2.3728	0.979	0.0094	0.966	0.123	19
	Test Stimulus 1.186 x 10^{-2}M.						
B/26c	0.8766	-2.0572	1.930	0.2855	0.719	0.203	18
B/28b	0.4239	-2.3728	1.651	0.2179	0.712	0.123	19

TABLE O.

EXPERIMENT III (b) RESULTS. SUBJECT C.

Test Stimulus 0.3261 x 10^{-2}M.

Case	Adapt.Odour Concn. (M x 10^{-2})	Log.Adapt. Odour Concn.	de'	Log.de'	N S+N	FPR	Temp. (°C.)
C/28a	1.441	-1.8412	3.444	0.5371	1.142	0.004	18
C/31b	0.4239	-2.3728	3.683	0.5662	1.714	0.008	19
	Test Stimulus 1.186 x 10^{-2}M.						
C/28a	1.441	-1.8412	4.349	0.6384	1.121	0.004	18

APPENDIX IV

APPENDIX IV

TABLE A.

EXPERIMENT I RESULTS. SUBJECT D.

Case	Saturator Temp. °C.	Threshold	FPR	Temp. (°C.)
D/4c	-17	+1.46	0.03	18
D/5a	-17	N.C.	0.13	18
D/6b	-17	N.C.	0	18
D/7c	-12	+1.44	0	18
D/8a	-12	+0.86	0	18
D/9b	-12	N.C.	0	18

TABLE B.
EXPERIMENT I RESULTS. SUBJECT E.

Case	Saturator Temp. °C.	Threshold	FPR	Temp. (°C.)
E/3c	-17	-1.14	0.09	18
E/4a	-17	N.C.	0.63	18
E/5b	-17	N.C.	0.64	18
E/6c	-12	-0.14	0.14	18
E/7a	-12	0.41	0.02	18
E/8b	-12	0.15	0.02	18

TABLE C.
EXPERIMENT I RESULTS. SUBJECT F.

Case	Saturator Temp. °C.	Threshold	FPR	Temp. (°C.)
F/4c	-17	+0.80	0	18
F/5a	-17	+0.33	0.03	18
F/6b	-17	+0.55	0	18
F/7c	-12	+0.08	0	18
F/8a	-12	+0.15	0	17
F/9b	-12	-0.01	0	18

TABLE D.
EXPERIMENT I RESULTS. SUBJECT G.

Case	Saturator Temp. °C.	Threshold	FPR	Temp. (°C.)
G/3c	-17	+0.41	0	18
G/4a	-17	-0.19	0.03	18
G/5b	-17	+0.02	0	18
G/6c	-12	+0.17	0	18
G/7a	-12	+0.41	0	17

Threshold is expressed in twofold steps from standard concentration (4% of saturation). N.C. Thresholds not calculable due to sudden cut-off or high FPR.

TABLE E.

EXPERIMENT II RESULTS. SUBJECT D.

Case	Test.Concn. (mm. Hg)	Log.Test Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
D/12b	0.299	-0.525	2.132	0.329	1.028	0.556	18
D/13c	0.149	-0.826	1.629	0.212	1.328	0.580	18
D/15b	0.597	-0.224	N.C.	-	-	0.397	18
D/16c	1.194	0.077	2.954	0.470	1.130	0.549	18
D/17a	2.389	0.378	N.C.	-	-	0.452	18

TABLE F.

EXPERIMENT II RESULTS. SUBJECT E.

Case	Test.Concn. (mm. Hg)	Log.Test Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
E/11b	0.149	-0.826	1.497	0.175	0.818	0.250	18
E/12c	0.149	-0.826	1.252	0.098	0.598	0.246	18
E/13a	0.299	-0.525	2.623	0.419	0.820	0.203	18
E/14b	0.597	-0.224	3.126	0.495	0.665	0.060	19
E/15c	1.194	0.077	N.C.	-	-	0	18
E/16a	2.389	0.378	N.C.	-	-	0.032	18

TABLE G.

EXPERIMENT II RESULTS. SUBJECT F.

Case	Test.Concn. (mm. Hg)	Log.Test Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
F/12b	0.149	-0.826	2.314	0.364	1.543	0.083	18
F/13c	0.149	-0.826	2.584	0.412	0.523	0.032	18
F/14a	0.299	-0.525	3.937	0.595	1.853	0.042	18
F/15b	0.597	-0.224	3.060	0.486	3.000	0.077	19
F/16c	1.194	0.077	N.C.	-	-	0	18
F/17a	2.389	0.378	N.C.	-	-	0.056	18

TABLE H.

EXPERIMENT II RESULTS. SUBJECT G.

Case	Test.Concn. (mm. Hg)	Log.Test Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
G/11b	0.149	-0.826	3.835	0.584	0.515	0.040	18
G/12c	0.149	-0.826	N.C.	-	-	0.040	18
G/13a	0.299	-0.525	4.145	0.618	3.651	0.024	18
G/14b	0.597	-0.224	N.C.	-	-	0.010	18
G/15c	1.194	0.077	N.C.	-	-	0.010	18
G/16a	2.389	0.378	N.C.	-	-	0.078	18

N.C. de' not calculable due to insufficient response categories. Sat.Temp. -

TABLE I.

EXPERIMENT III (b) RESULTS. SUBJECT D.

Test.Concn. (mm. Hg)	Log.Test Concn.	Adapt.Odour Concn. (mm. Hg)	Log.Adapt. Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
1.194	0.077	0	-	N.C.	-	-	0.468	18
1.194	0.077	0.171	-0.768	N.C.	-	-	0.410	21
1.194	0.077	0.237	-0.626	N.C.	-	-	0.345	18
1.194	0.077	0.417	-0.380	N.C.	-	-	0.480	19
1.194	0.077	0.692	-0.160	N.C.	-	-	0.750	20
1.194	0.077	1.018	0.008	N.C.	-	-	0.639	20
0.597	-0.224	0	-	2.815	0.450	1.852	0.468	18
0.597	-0.224	0.171	-0.768	N.C.	-	-	0.410	21
0.597	-0.224	0.237	-0.626	N.C.	-	-	0.345	18
0.597	-0.224	0.417	-0.380	2.230	0.348	0.745	0.480	19
0.597	-0.224	0.692	-0.160	0.460	-0.337	0.779	0.750	20
0.597	-0.224	1.018	0.008	0.913	-0.040	1.586	0.639	20
0.299	-0.525	0	-	2.347	0.371	1.991	0.468	18
0.299	-0.525	0.171	-0.768	1.869	0.272	1.697	0.410	21
0.299	-0.525	0.237	-0.626	0.510	-0.292	0.598	0.345	18
0.299	-0.525	0.417	-0.380	0.991	-0.004	1.119	0.480	19
0.299	-0.525	0.692	-0.160	0.155	-0.810	1.057	0.750	20
0.299	-0.525	1.018	0.008	N.C.	-	-	0.639	20
0.149	-0.826	0	-	1.070	0.029	1.449	0.468	18
0.149	-0.826	0.171	-0.768	0.744	-0.128	1.261	0.410	21
0.149	-0.826	0.237	-0.626	0.382	-0.418	1.227	0.345	18
0.149	-0.826	0.417	-0.380	0.032	-1.495	0.934	0.480	19
0.149	-0.826	0.692	-0.160	0.344	-0.463	0.815	0.750	20
0.149	-0.826	1.018	0.008	0.284	-0.547	1.306	0.639	20
0.075	-1.127	0	-	0.670	-0.174	1.451	0.468	18
0.075	-1.127	0.171	-0.768	1.582	0.199	2.115	0.410	21
0.075	-1.127	0.237	-0.626	1.042	0.018	1.543	0.345	18
0.075	-1.127	0.417	-0.380	0.798	-0.098	1.260	0.480	19
0.075	-1.127	0.692	-0.160	0.155	-0.810	1.146	0.750	20
0.075	-1.127	1.018	0.008	0.226	-0.646	1.419	0.639	20
0.037	-1.428	0	-	0.418	-0.378	1.312	0.468	18
0.037	-1.428	0.171	-0.768	0.877	-0.057	1.141	0.410	21
0.037	-1.428	0.237	-0.626	0.605	-0.218	1.263	0.345	18
0.037	-1.428	0.417	-0.380	0.214	-0.670	0.895	0.480	19
0.037	-1.428	0.692	-0.160	0.226	-0.646	1.006	0.750	20
0.037	-1.428	1.018	0.008	0.118	-0.928	1.026	0.639	20

N.C. de' not calculable due to insufficient response categories.

TABLE J.

EXPERIMENT III (b) RESULTS. SUBJECT E.

Test.Concn. (mm. Hg)	Log.Test Concn.	Adapt.Odour Concn. (mm. Hg)	Log.Adapt. Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
1.194	0.077	0	-	N.C.	-	-	0.106	18
1.194	0.077	0.171	-0.768	3.290	0.517	0.247	0.152	19
1.194	0.077	0.237	-0.626	N.C.	-	-	0.155	21
1.194	0.077	0.417	-0.380	N.C.	-	-	0.104	19
1.194	0.077	0.692	-0.160	N.C.	-	-	0.080	19
1.194	0.077	1.018	0.008	2.876	0.459	1.137	0.080	20
0.597	-0.224	0	-	2.895	0.462	0.462	0.106	18
0.597	-0.224	0.171	-0.768	1.803	0.256	0.256	0.152	19
0.597	-0.224	0.237	-0.626	2.334	0.368	0.368	0.155	21
0.597	-0.224	0.417	-0.380	1.465	0.166	0.166	0.104	19
0.597	-0.224	0.692	-0.160	0.974	-0.011	-0.011	0.080	19
0.597	-0.224	1.018	0.008	0.442	-0.355	-0.355	0.080	20
0.299	-0.525	0	-	1.782	0.251	0.727	0.106	18
0.299	-0.525	0.171	-0.768	1.489	0.173	0.591	0.152	19
0.299	-0.525	0.237	-0.626	1.792	0.253	1.007	0.155	21
0.299	-0.525	0.417	-0.380	0.525	-0.280	0.745	0.104	19
0.299	-0.525	0.692	-0.160	0.565	-0.248	1.013	0.080	19
0.299	-0.525	1.018	0.008	0.788	-0.104	1.036	0.080	20
0.149	-0.826	0	-	0.801	-0.096	0.819	0.106	18
0.149	-0.826	0.171	-0.768	0.376	-0.425	0.884	0.152	19
0.149	-0.826	0.237	-0.626	0.465	-0.333	0.676	0.155	21
0.149	-0.826	0.417	-0.380	0.126	-0.900	0.713	0.104	19
0.149	-0.826	0.692	-0.160	0.501	-0.300	1.329	0.080	19
0.149	-0.826	1.018	0.008	0.638	-0.195	1.640	0.080	20
0.075	-1.127	0	-	0.672	-0.173	0.840	0.106	18
0.075	-1.127	0.171	-0.768	0.450	-0.347	0.917	0.152	19
0.075	-1.127	0.237	-0.626	0.271	-0.567	0.826	0.155	21
0.075	-1.127	0.417	-0.380	0.186	-0.731	1.202	0.104	19
0.075	-1.127	0.692	-0.160	0.552	-0.258	1.539	0.080	19
0.075	-1.127	1.018	0.008	0.440	-0.357	0.849	0.080	20
0.037	-1.428	0	-	0.315	-0.494	0.850	0.106	18
0.037	-1.428	0.171	-0.768	0.288	-0.541	0.996	0.152	19
0.037	-1.428	0.237	-0.626	0.321	-0.494	0.815	0.155	21
0.037	-1.428	0.417	-0.380	0.491	-0.309	1.277	0.104	19
0.037	-1.428	0.692	-0.160	0.486	-0.313	1.039	0.080	19
0.037	-1.428	1.018	0.008	0.500	-0.301	1.233	0.080	20

N.C. de' not calculable due to insufficient response categories.

TABLE K.

EXPERIMENT III (b) RESULTS. SUBJECT F.

Test.Concn. (mm. Hg)	Log.Test Concn.	Adapt.Odour Concn. (mm. Hg)	Log.Adapt. Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
1.194	0.077	0	-	N.C.	-	-	0.019	18
1.194	0.077	0.171	-0.768	N.C.	-	-	0.026	19
1.194	0.077	0.237	-0.626	N.C.	-	-	0.012	21
1.194	0.077	0.417	-0.380	N.C.	-	-	0.040	19
1.194	0.077	0.692	-0.160	N.C.	-	-	0.012	19
1.194	0.077	1.018	0.008	N.C.	-	-	0.016	20
0.597	-0.224	0	-	N.C.	-	-	0.019	18
0.597	-0.224	0.171	-0.768	N.C.	-	-	0.026	19
0.597	-0.224	0.237	-0.626	N.C.	-	-	0.012	21
0.597	-0.224	0.417	-0.380	3.153	0.499	0.616	0.040	19
0.597	-0.224	0.692	-0.160	N.C.	-	-	0.012	19
0.597	-0.224	1.018	0.008	3.224	0.508	1.217	0.016	20
0.299	-0.525	0	-	4.335	-	-	0.019	18
0.299	-0.525	0.171	-0.768	N.C.	-	-	0.026	19
0.299	-0.525	0.237	-0.626	3.022	0.480	0.269	0.012	21
0.299	-0.525	0.417	-0.380	N.C.	-	-	0.040	19
0.299	-0.525	0.692	-0.160	N.C.	-	-	0.012	19
0.299	-0.525	1.018	0.008	N.C.	-	-	0.016	20
0.149	-0.826	0	-	3.549	-	-	0.019	18
0.149	-0.826	0.171	-0.768	N.C.	-	-	0.026	19
0.149	-0.826	0.237	-0.626	2.360	0.373	0.500	0.012	21
0.149	-0.826	0.417	-0.380	2.551	0.407	1.023	0.040	19
0.149	-0.826	0.692	-0.160	3.220	0.508	0.661	0.012	19
0.149	-0.826	1.018	0.008	3.002	0.477	0.831	0.016	20
0.075	-1.127	0	-	3.013	0.479	1.112	0.019	18
0.075	-1.127	0.171	-0.768	2.692	0.430	0.903	0.026	19
0.075	-1.127	0.237	-0.626	2.254	0.353	0.836	0.012	21
0.075	-1.127	0.417	-0.380	2.132	0.329	1.384	0.040	19
0.075	-1.127	0.692	-0.160	2.762	0.441	0.843	0.012	19
0.075	-1.127	1.018	0.008	2.470	0.393	0.574	0.016	20
0.037	-1.428	0	-	1.505	0.178	0.776	0.019	18
0.037	-1.428	0.171	-0.768	1.433	0.156	0.757	0.026	19
0.037	-1.428	0.237	-0.626	1.542	0.188	1.153	0.012	21
0.037	-1.428	0.417	-0.380	1.484	0.172	1.043	0.040	19
0.037	-1.428	0.692	-0.160	1.227	0.089	0.719	0.012	19
0.037	-1.428	1.018	0.008	1.774	0.249	1.225	0.016	20

N.C. de' not calculable due to insufficient response categories.

TABLE L.

EXPERIMENT III (b) RESULTS. SUBJECT G.

Test.Concn. (mm. Hg)	Log.Test Concn.	Adapt.Odour Concn. (mm. Hg)	Log.Adapt. Concn.	de'	Log.de'	N / S+N	FPR	Temp. (°C.)
1.194	0.077	0	-	N.C.	-	-	0.220	18
1.194	0.077	0.171	-0.768	N.C.	-	-	0.319	21
1.194	0.077	0.237	-0.626	N.C.	-	-	0.409	18
1.194	0.077	0.417	-0.380	N.C.	-	-	0.409	19
1.194	0.077	0.692	-0.160	N.C.	-	-	0.563	20
1.194	0.077	1.018	0.008	N.C.	-	-	0.389	20
0.597	-0.224	0	-	N.C.	-	-	0.220	18
0.597	-0.224	0.171	-0.768	3.230	0.509	0.485	0.319	21
0.597	-0.224	0.237	-0.626	2.526	0.402	0.713	0.409	18
0.597	-0.224	0.417	-0.380	N.C.	-	-	0.409	19
0.597	-0.224	0.692	-0.160	0.935	-0.029	0.887	0.563	20
0.597	-0.224	1.018	0.008	N.C.	-	-	0.389	20
0.299	-0.525	0	-	2.625	0.419	0.732	0.220	18
0.299	-0.525	0.171	-0.768	2.012	0.304	0.881	0.319	21
0.299	-0.525	0.237	-0.626	1.269	0.104	0.831	0.409	18
0.299	-0.525	0.417	-0.380	1.273	0.105	1.287	0.409	19
0.299	-0.525	0.692	-0.160	N.C.	-	-	0.563	20
0.299	-0.525	1.018	0.008	N.C.	-	-	0.389	20
0.149	-0.826	0	-	1.536	0.186	0.994	0.220	18
0.149	-0.826	0.171	-0.768	1.137	-0.056	0.957	0.319	21
0.149	-0.826	0.237	-0.626	0.158	-0.801	1.186	0.409	18
0.149	-0.826	0.417	-0.380	0.469	-0.329	1.289	0.409	19
0.149	-0.826	0.692	-0.160	0.101	-0.996	1.184	0.563	20
0.149	-0.826	1.018	0.008	N.C.	-	-	0.389	20
0.075	-1.127	0	-	1.580	0.199	1.562	0.220	18
0.075	-1.127	0.171	-0.768	0.734	-0.134	1.599	0.319	21
0.075	-1.127	0.237	-0.626	0.257	-0.590	1.261	0.409	18
0.075	-1.127	0.417	-0.380	N.C.	-	-	0.409	19
0.075	-1.127	0.692	-0.160	0.255	-0.594	1.178	0.563	20
0.075	-1.127	1.018	0.008	0.982	-0.008	1.841	0.389	20
0.037	-1.428	0	-	0.580	-0.237	1.143	0.220	18
0.037	-1.428	0.171	-0.768	0.617	-0.210	0.981	0.319	21
0.037	-1.428	0.237	-0.626	0.210	-0.678	1.186	0.409	18
0.037	-1.428	0.417	-0.380	0.133	-0.876	0.940	0.409	19
0.037	-1.428	0.692	-0.160	0.220	-0.658	1.083	0.563	20
0.037	-1.428	1.018	0.008	1.271	0.104	1.899	0.389	20

N.C. de' not calculable due to insufficient response categories.

APPENDIX V

APPENDIX V

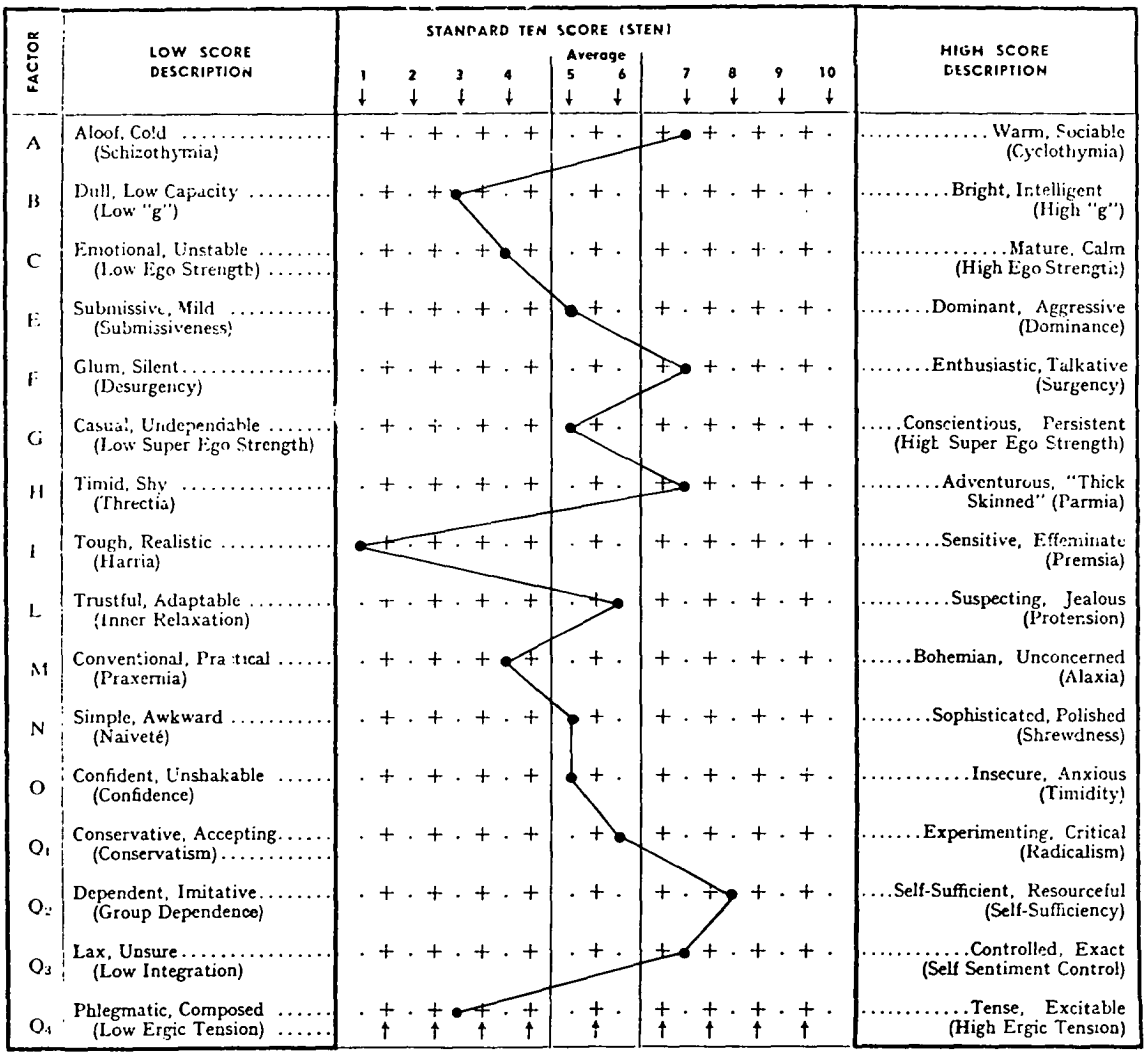


Fig. A. 16 PF Profile. SUBJECT A.

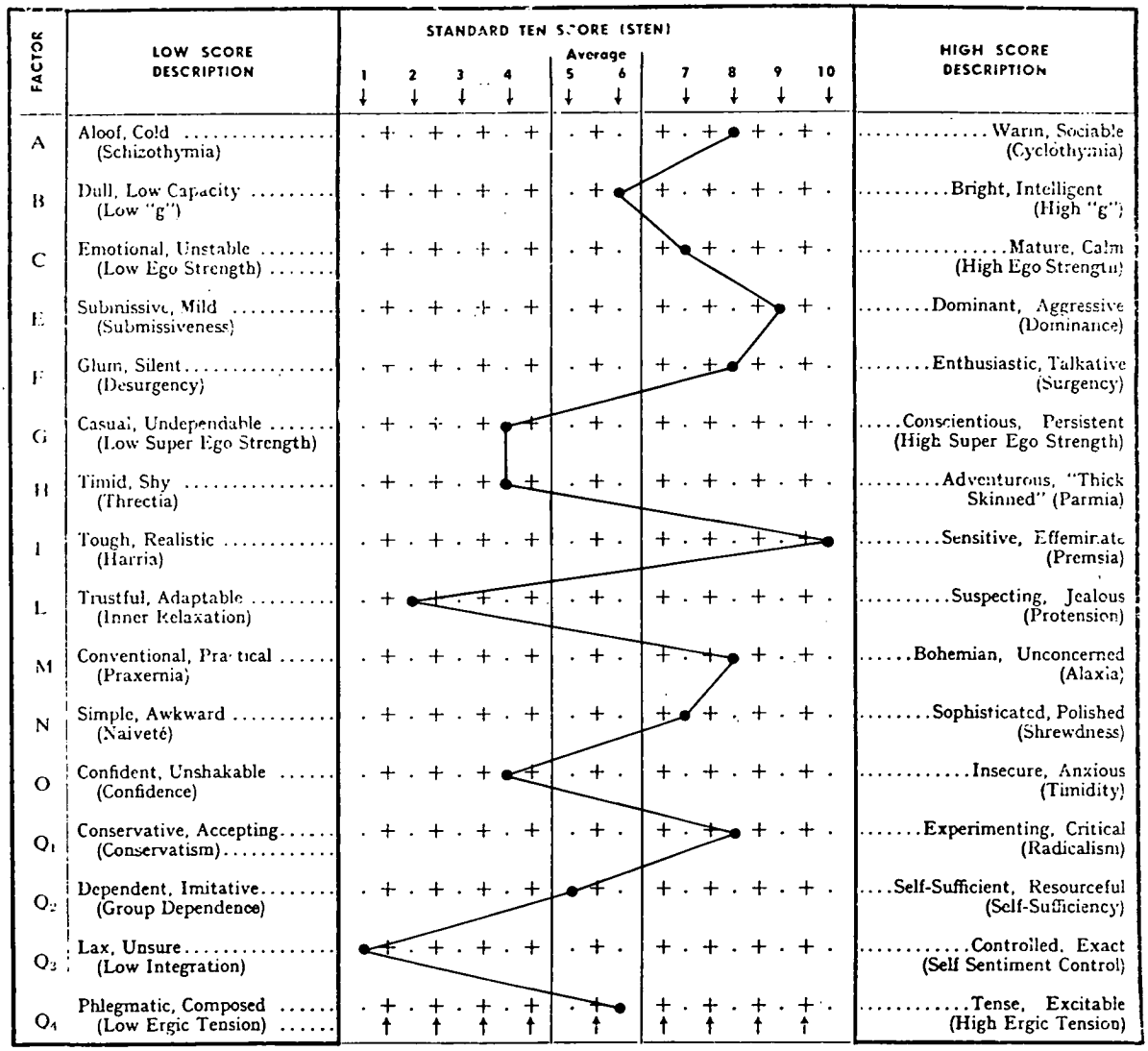


Fig. B. 16 PF Profile. SUBJECT B.

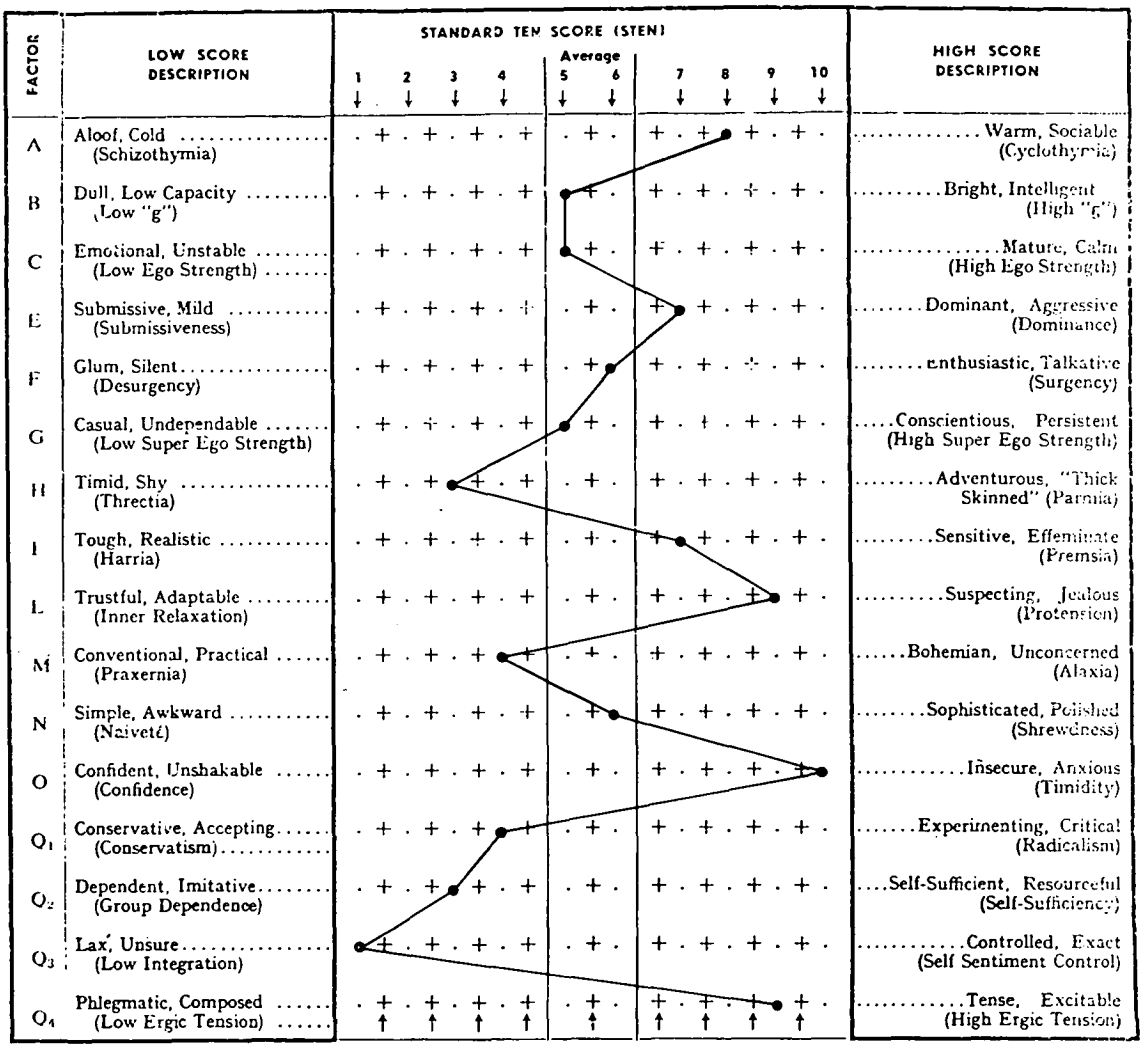


Fig. C. 16 PF Profile. SUBJECT C.

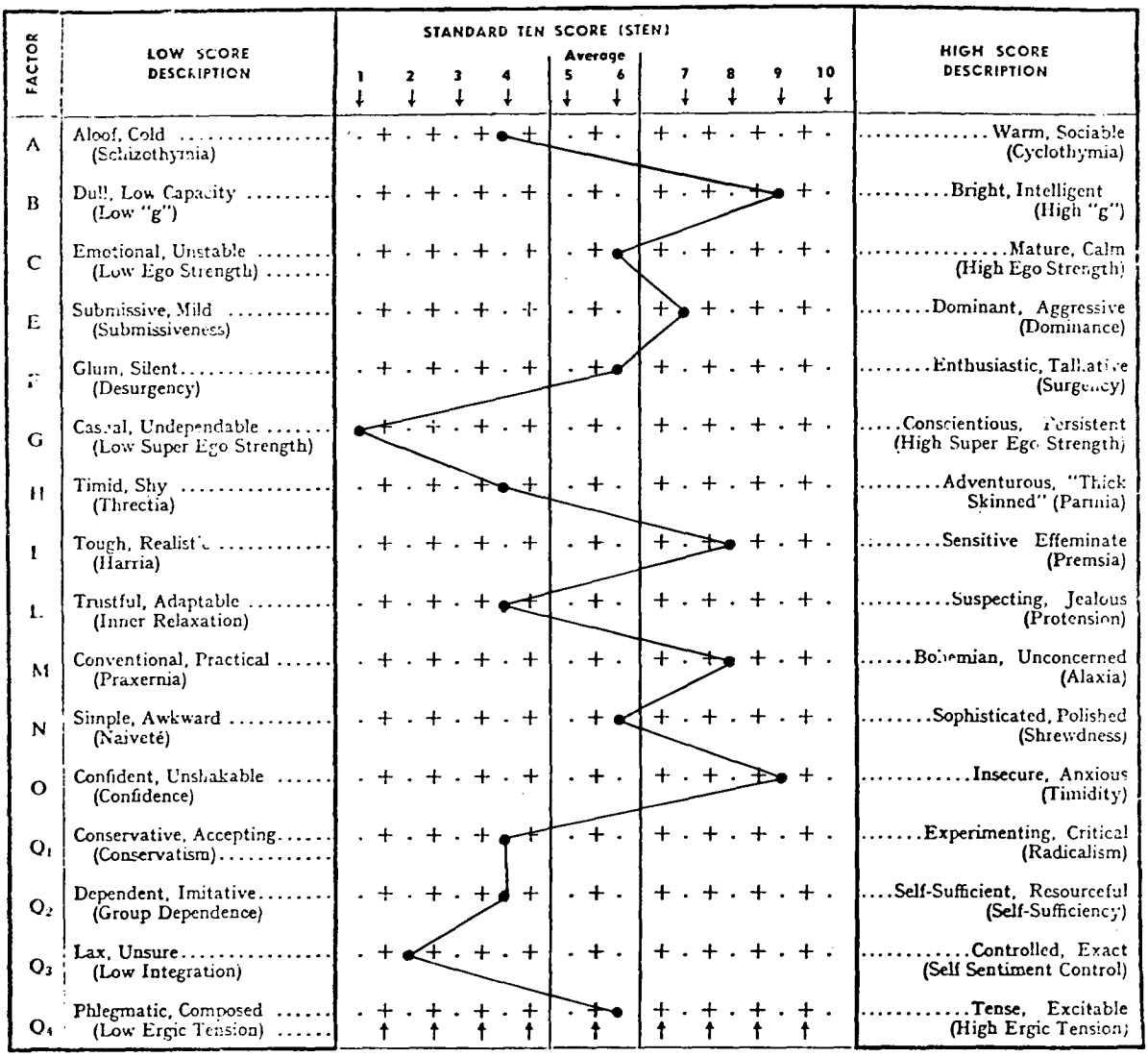


Fig. D. 16 PF Profile. SUBJECT D.

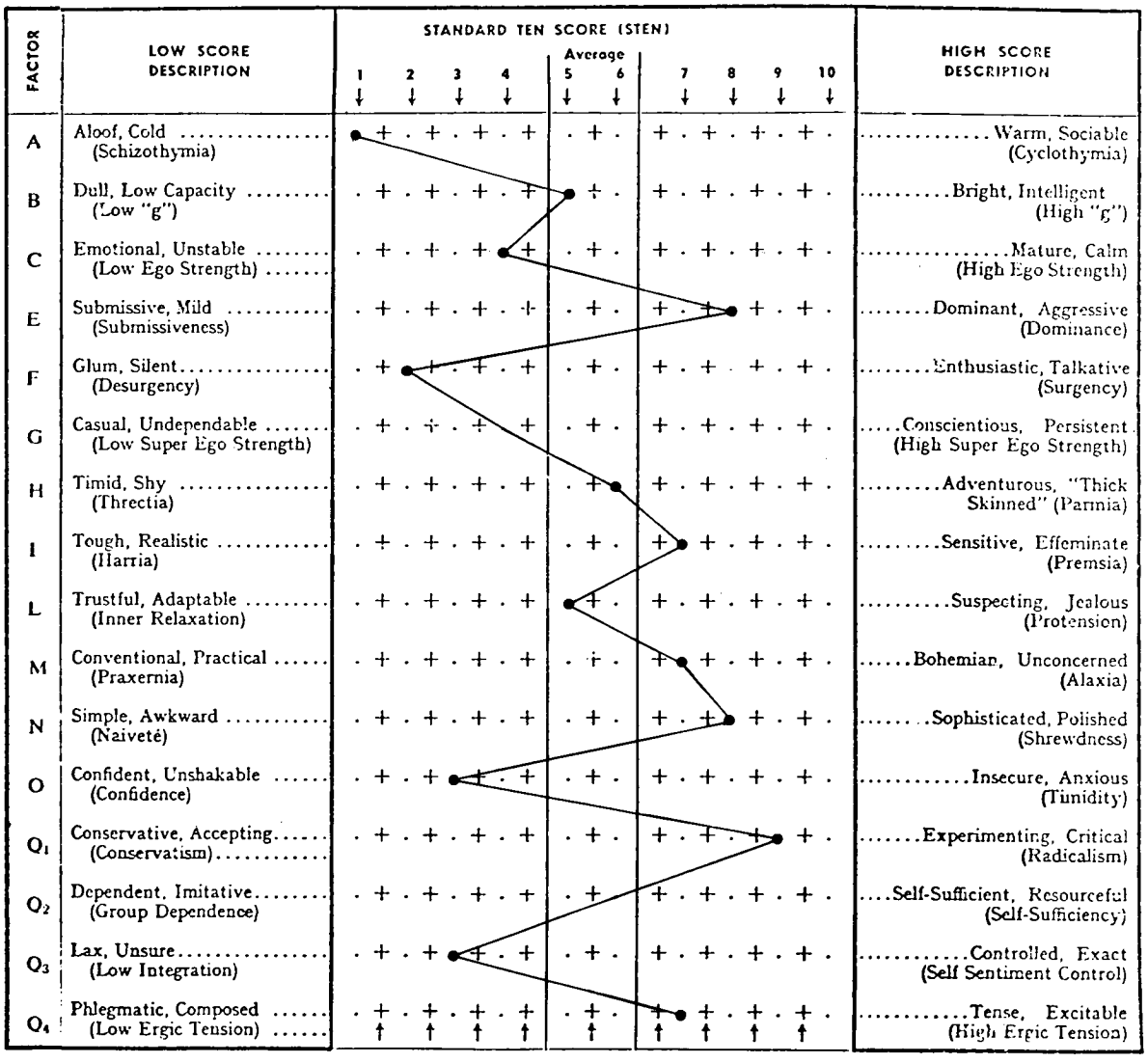


Fig. E. 16 PF Profile. SUBJECT E.

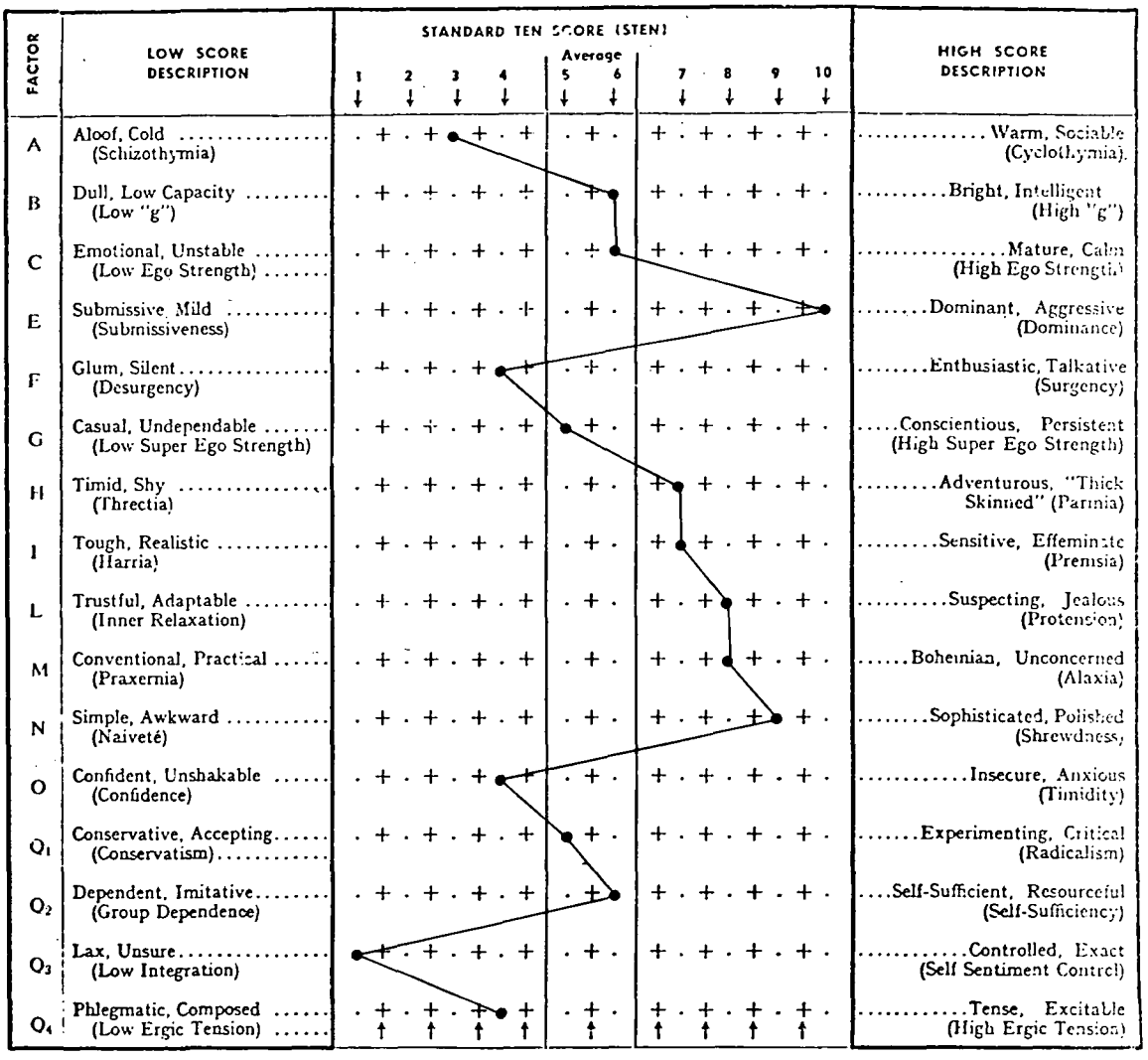


Fig. F. 16 PF Profile. SUBJECT F.

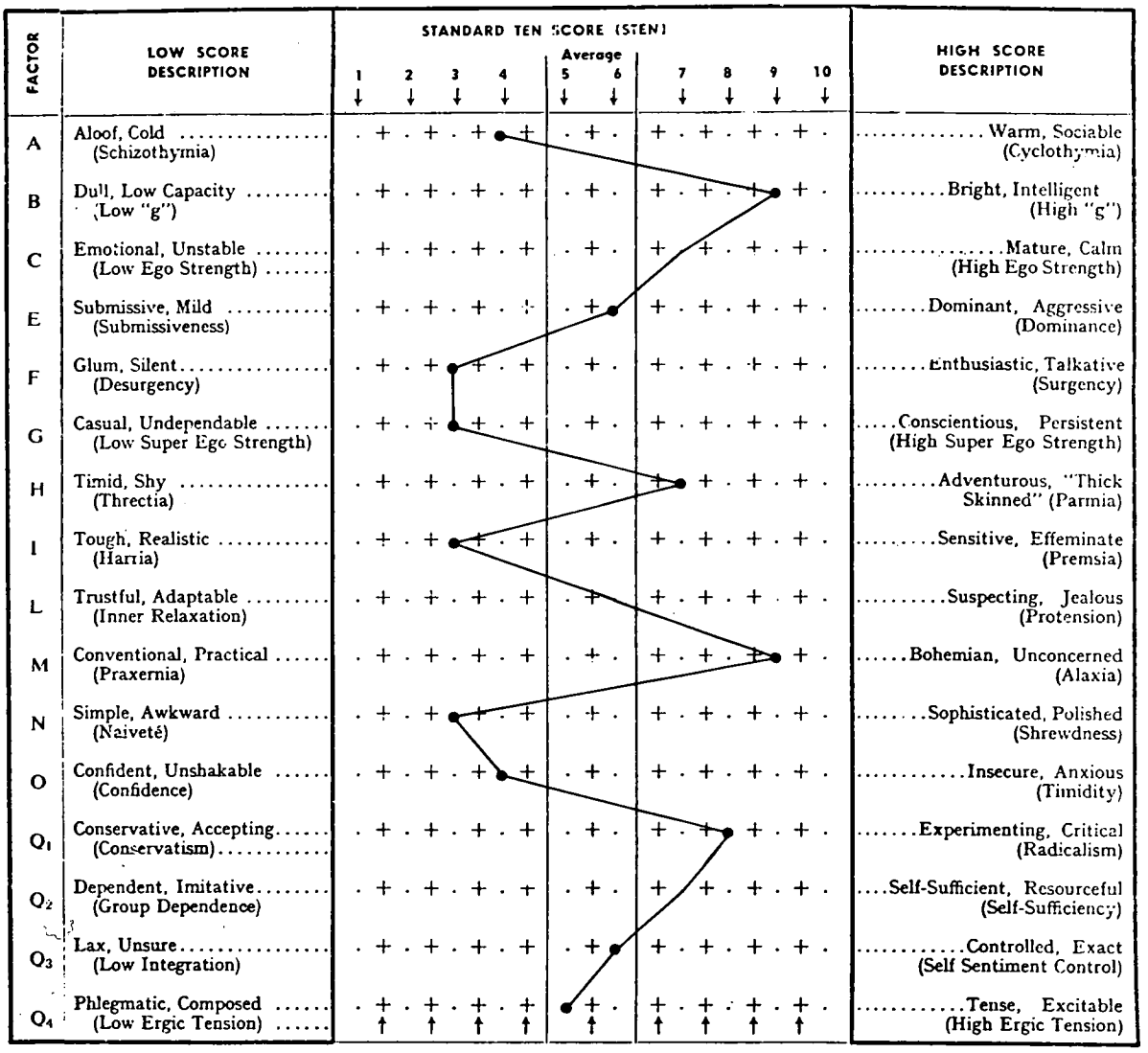


Fig. G. 16 PF Profile. SUBJECT G.